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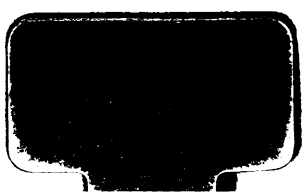

READINGS IN SCIENCE:

BEING EXPLANATIONS OF SOME OF THE MOST INTERESTING

APPEARANCES AND PRINCIPLES IN NATURAL PHILOSOPHY,

EXPRESSED IN SIMPLE LANGUAGE, AND ILLUSTRATED BY FAMILIAR EXAMPLES.

THE FIFTH EDITION, REVISED.

PUBLISHED UNDER THE DIRECTION OF THE COMMITTEE OF GENERAL LITERATURE AND EDUCATION, APPOINTED BY THE SOCIETY FOR PROMOTING CHRISTIAN KNOWLEDGE.

LONDON:
JOHN W. PARKER AND SON, WEST STRAND.
1853.

In f. C. 14.

PREFACE.

IN this volume some of the most important principles of science, and their practical applications, are treated in a more popular manner than is usual in works of an exclusively scientific nature.

A few sections at the beginning are devoted to one or two simple subjects. The TRIANGLE is selected as an instructive, and at the same time a very striking example; and some of its most useful applications are explained and illustrated. A common WATCH, one of the most familiar, as it is also one of the neatest, instances of mechanical combination, is then described. This is done with considerable minuteness of detail; showing how many facts, connected with the various properties and uses of substances, must have been studied with the greatest exactness, before a watch could be brought to its present state of perfection.

After suitable references to these subjects, it was judged best to take some great natural principle as the groundwork of further illustrations. LIGHT was chosen as the first, on account of its beauty, its familiarity, and the number of its uses; and a view is given of its most remarkable phenomena, of the laws of optics, and the nature and uses of optical instruments. A short sketch is then introduced, of the

laws of DOUBLE REFRACTION and POLARIZATION, which, though often mentioned, it is believed, have not hitherto been popularly explained.

The doctrine of light leads naturally and almost necessarily to that of HEAT. Its consideration, therefore, follows that of LIGHT. The relationship between the two is first pointed out; and then the differences of the modes in which they appear; care being taken to explain and guard against numerous errors which exist respecting heat.

The doctrine of heat involves the state of bodies, the different attractions by which the several parts, or the elements, of a compound are held together, and the specific actions by which these are strengthened or weakened. The various processes by which bodies are changed from the SOLID to the LIQUID, the VAPOROUS, and the GASEOUS states, and many chemical changes, both as respects form and composition, are here brought under review. An opportunity is thus presented for illustrating principles by their application to the useful arts; such as the making of GLASS, BRICKS, and POTTERY.

The leading phenomena of COMBUSTION, and the nature and action of FIRE and FLAME, are then noticed at some length; followed by an account of the most brilliant, as well as the most useful, kinds of ARTIFICIAL LIGHT.

Next succeeds a general outline of ELECTRICITY, as usually divided into common and voltaic, then MAGNETISM and ELECTRO-MAGNETISM; with descriptions of some of the most useful forms of electrical and

electro-magnetic apparatus. The application of electricity in that wonderful invention, the TELEGRAPH—has not been omitted; just so much, as it is hoped, being said about it as to make its operations intelligible to all classes of readers.

Another useful invention of recent date—the STEREOSCOPE—has received attention. The instrument is described and illustrated, and the principle of binocular vision explained. This is followed by a short account of PHOTOGRAPHY, and some useful hints respecting Daguerreotype portraits. The volume closes with a notice of the MICROSCOPE, and illustrations of some remarkable microscopic objects.

In the execution of this task, the desire has been to be simple, to be original, to be accurate, and to be useful. Technical forms of expression have been as much as possible avoided; and, where such words or phrases were deemed the most applicable, they have been explained. For illustrations, familiar subjects have been preferred; and when experiments are alluded to, they are generally such as may be readily performed. More attention has been paid to clearness in the leading and general principles than to the refinements of system; and the opening up of connecting views between one subject and another, has been thought more useful in itself, and more likely to excite a love of science, than the following of any single subject into all its minute details. The relations between Art and Nature, and between one part of nature and another, have always been carefully explained; and, when the inquiry has pointed

upwards, from nature to the Divine Author of nature, the reverential expression has not been withheld.

Little that is new in science can be expected in a popular volume; but still there will be found many instances in which the investigations or the analyses have been carried somewhat further than is usually done, and others in which inferences have been pointed out, where more frequently principles only are stated. In the illustrations, novelty has not been sought at the expense of effect; but where two illustrations seemed equally in point, the more novel has been preferred. On these grounds it is hoped that the volume will not be deemed unworthy of a place in the libraries of the learned; whilst, for the reasons already stated, it is intended that it should be especially welcome to the youthful and general reader.

Style, in a scientific work, is of secondary importance. The qualities which have been aimed at in the present volume are plainness and vigour, rather than polish and ornament.

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READINGS IN SCIENCE.

Section I. Science generally and its Uses.

The word Science is formed of two Latin words—*scire*, which means 'to know,' and *ens*, which means 'being,' or 'existence' or 'reality;' so that the meaning of it is, 'the knowledge of that which really is,'—true knowledge —the knowledge of the truth. It follows from this definition, that everything which we can know is science—that all true knowledge which we have, or can have, of the visible creation, as well as the natural conviction of the existence, and power, and wisdom, and goodness of God the Creator, which never fails to arise when we view creation aright, is *science*. Besides this knowledge, and the uses which can be made of it, we can have no other, except of the doctrines of our holy religion; and these are a direct revelation made to man by God himself.

Both these great divisions of human study and understanding are so beautifully adapted to their several purposes, that it is impossible to avoid tracing them to the same wisdom and goodness; and, excepting that the one is for life in this world only, and the other for life without end, both have equal claims on our attention and gratitude.

One principal distinction between them is, that religion is for all people, and, in its substantial advantages, for all people equally, whatever may be their acquirements and condition in this world; whereas science varies with all the varying conditions of men, so that every man may acquire that portion which is most necessary for himself in order to make him successful in life, ready in the per-

formance of his duty, and consequently happy and respected. Men who work for their bread from day to day, men who superintend and direct the labour of others, and men who communicate instruction, all require different kinds of science. Not only should they be differently prepared or educated for their respective duties, but their habits of thinking should be different; for very great differences arise from the situations in which they are placed, and changes occur in the subjects about which they are occupied; and they should be always ready to accommodate themselves to these. Thus, it would be very unwise in a shepherd, or a ploughman, to spend all his leisure time in studying the art of managing a ship, and it would be just as unwise in a sailor to spend his time in studying the keeping of sheep or the ploughing of land.

These are broad and general instances, and in them it is to the art rather than the science that allusion is made. Generally speaking, it is only from what men do that we can find out what they know; although it is always very easy to find out whether a man has, or has not, the science or knowledge of that which he is doing. So also we may discover that the man who has not the science must, in almost all cases, perform twice as much labour as the man who has it, and very often a great deal more. Besides, it is not possible for a man thoroughly to like what he does not understand; and therefore he who is ignorant of that about which he is occupied is generally careless and indolent, getting away from it on the most trifling occasions. Such a man, consequently, never attains any name or respectability in his particular vocation, but remains a mere drudge—a careless, grumbling, and miserable drudge —throughout life. No small portion of the poverty and wretchedness, and not very few of the crimes which stain the very best societies, have their origin in people not so studying their callings and occupations as to have the knowledge or science of them, in order that they may love them. The loving of anything so immediately follows the knowing of it, that we can with difficulty say, in some

instances, which is the first, though from the nature of the thing it must be the knowledge.

But though, for immediate personal service to ourselves, the practical knowledge, or technical science, of our callings or professions, whatever they may be, is to us the most necessary of all science; yet, unless we go a great deal further, we shall not be able to promote the improvement even of that.

Whatever some may think, there is no man in any society, even though there be not another of the same profession in it, who is independent of that society, or can carry on even that employment of which he is the sole and only professor, without the rest of the society, any more than a hand can grasp, or an eye see, without the other parts of a human body. This consideration should correct our silly pride, and foster nobler feelings in that society of which we are members. It should expand our minds beyond our own little occupations, to the study of those collateral matters, by which we might attain to greater perfection, and promote, nay insure, success in our own labour. We should not make our neighbour's trade our occupation, any more than we should make his affairs the subject of our discourse; but still we should know as much about it as to be able at once to see the points on which we can be useful to each other. The individual, however important he may be in himself, is to society only as the hand or the eye is to the body. There have been many individual men who have lived in honour, and left to their country legacies which, without much exaggeration, we call inestimable; but there never yet lived a man whom his country could not have much better done without, than he could have done without his country.

But if the country in which we are to use our science or knowledge form one society, and we be only small parts of that society; so nature is one, and the subjects of our science—of that part of it which is practically useful to us—are also but a small part of that whole. Further, as in the very utmost of our research and study on any one

subject, we never can tell how great may be the unknown part of the science of that subject compared with what we know; we never can be sure that what we pass over as foreign to our purpose may not be the very thing which, if we only studied it a little more attentively, would just answer that purpose. The history of science is full of accounts of discoveries which were all but made by the men of one generation, but which they missed; and the world lost the benefit for ages, because the road to them seemed too plain and simple to lead to anything of importance. This fact should teach us to despise nothing; and though it may not be consistent with our duty to ourselves and to society, to go much out of our way in order to learn, yet we should make a point of endeavouring to understand all that comes in our way.

In order to do this properly many things are necessary; but there are two of such primary importance that all should be furnished with them. One of these is a scientific habit; and the other a knowledge of the outline of all the more important and general branches of science. The first might be denominated "the workman," and the second, "the working tools." If we have not both always in readiness, we must miss many opportunities; and one opportunity not improved is always a loss, even though one exactly like it occur again; for if we had taken advantage of the first, the time of the second would have been applied to something else, and in the interim we might have been enjoying the advantages of the first.

Our natural desire for knowledge is merely a desire for novelty—a disposition not to be satisfied with what we know already, but without any guide save experience to direct us to what is useful to be known; and, as in early life we have little experience of our own, we must be nurtured into the method of acquiring knowledge, just as we are nursed into bodily strength. This is one of the uses, indeed it is the chief use, of education; for education is nothing more than pointing out the way in which other people obtained information, and as all minds are similar

in their general structure, this is sufficient. Till we have acquired the habit, it is very obvious, that though we may learn by accident, we cannot learn by design, because design, though it may be the cause of future knowledge, is the effect of former knowledge. We can have no design about that of which we are ignorant. But, after we have once acquired the scientific habit, there is no limit beyond which, if we have time and opportunity, we may not go; only we must have a beginning—must be indebted to teaching of some sort for the first steps of our progress. There are no Isaac Newtons, or even James Fergusons, among men in the rude state, where there have been no former men of science, no institutions for the encouragement of science, and no books for instruction in it. Of all men who have attained any considerable celebrity for popular knowledge in mechanical science, James Ferguson, perhaps, approaches the nearest to what we are accustomed to call self-taught; but he confesses that he learnt the first lesson from his father, who was raising with a lever the roof of his house, in order to repair it. If we could get at the facts in other cases, we should find that there has generally been a teacher, either by precept or example —a little of the latter often going as far as a great deal of the former. There is both encouragement and warning in this. Little will do, but we must have that little. Were this not the case, we should find science everywhere; whereas we never find any native science in countries where regular society has not existed; and we find, too, that in all cases where the fabric of society is overturned, whether the cause be from without or from within, science vanishes, or is buried in the ruins.

Section II. A Scientific Habit.

A SCIENTIFIC habit is the constant practice of never letting any object which comes before us pass, till we know all that can be known about its nature and uses. A person without such a habit is in much the same condition as the

untutored savage, even though he live in the best-informed and best-regulated society. Morally, indeed, he is far worse. If the poor savage had the opportunity, there is little doubt but he would gladly avail himself of it; whereas the negligent man in an informed and civilized country has the opportunity, and wickedly and cruelly—cruelly even to himself—neglects it. The pains which the New Zealander bestows in carving his canoe, his paddle, and his club, and even that which the New Hollander bestows on his stone-knife and spear-head, and the diligence with which he practises until he can throw the spear, all tend to show how ready these people would be to follow more important employments, if they had the habitual examples before them as we have, though we too often neglect them.

We must not despise the individual portions of knowledge within our reach, however small they may appear in comparison with the masses around us. Large mountains are formed of little stones; the ocean, of drops so light that they mount up in the air and form clouds; the earth, nay, the universe itself, is made of atoms so small, that we could not see a collection of even many millions of them. It is the same with science (which is the knowledge of substance) as with substance itself; and the simplest truth may be the result of a thousand thoughts, and the complete application of that truth the continued work of a hundred generations. Before common penknives could have been brought to so much perfection that good ones can be sold for little more than a shilling a dozen, perhaps the process of improving them went through as many hands as there are now at work in all Sheffield. The names of all, save a very few, and they but imperfectly known, have perished; but they had their reward in their day, in the feeling that they did not neglect their opportunities.

In consequence of the combined labours of scientific men, applied to the different departments of art, the poorest man in England can now, if he be at all careful, have as many axes as he requires; but when Allan Cunningham,

the botanist, was in the South Sea Islands, he purchased the bridal robe of a princess for three axe-heads; and he might have obtained a domain as ample as that of the wealthiest baron in England for a single chisel. This happened, not in a place where the people were indolent and ignorant, and where the tools were matters of mere wonder, but in New Zealand, where the people are industrious, and can handle axes and chisels to good purpose.

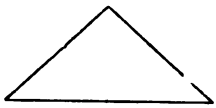
Now, though the whole process which has made the relative values of property and labour in the two countries so very different be immense, each of the steps of it has been so small, that almost the whole of them have passed unheeded. It is all the result of science; and the contrast on our side is all in the way of benefit. We cannot add to the geographical extent of our island; but we have so improved it that many single miles of it are worth whole kingdoms, in everything that man can enjoy. The whole has been brought about, too, not by some few brilliant discoveries (for though we have had our full share of *them*, they are consequences before they are causes), but by a steady and increasing scientific habit among a portion, at least, of all ranks and professions.

And what is this scientific habit to which the world generally, and we in particular, are so much indebted? It is the simplest matter in the world,—nothing but to notice *all* that we see and hear, and compare one thing with another—that which all children do of their own accord; only where there is much of art, and they are as yet merely nature, we have to guide them in their choice at first, just as we have to find them food and clothing, and, in the earliest stages of their lives, have to put the clothing on their backs, and the food into their mouths.

They who have not this habit continue all their lives very much in the same state as little babes. They see colours, and hear noises, and have their other senses affected; but unless it bears upon some of their animal gratifications, the sensation passes as it comes, and might just as well not have been produced.

Section III. Instance of a Triangle.

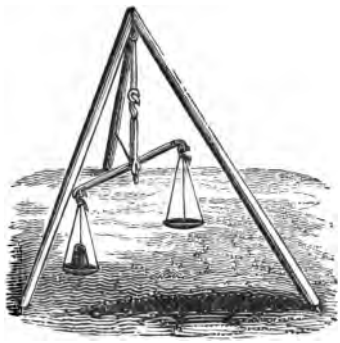
Any object, even the most simple, will serve for an illustration here. Let us take that of a plane triangle, or three-cornered and straight-sided figure, which is surface merely, and the very simplest of all surfaces, because it is bounded by straight lines, which are the simplest of all lines, and by only three of them, the very smallest number that will bound any figure.



The word "triangle" is in so common use, that there are probably not many persons in England who do not know a triangle at sight, and also remember that it has three sides and three corners; but they who have not been a little habituated to the science of triangles know very little more about it than has been stated; and truly, for any useful purpose, that is next to nothing.

Take the specimen given, and ask them whether it be the three black lines, or the piece of white paper within them, which is the triangle, and they will not be able to tell. It is not the lines; for if three lines, all of the same length, were drawn the one below the other, there would be the very same number and measure of lines, and yet there would be no triangle.

As little is it the paper; for take away the lines, and there would be no triangle there. Other parties would give you very different notions, if you questioned them about a triangle. Ask a sailor, and the chance is that he would reply, "Difference of latitude, departure, and distance," as the lines to which sailors give those names form a triangle on a chart. Ask a soldier, and if he were a man of unsoldierlike conduct, or belonged to a regiment of loose habits, he would think of a machine sometimes used in military punishments. Ask a porter, accustomed to assist in weighing heavy goods by means of a moveable beam and scales, and he would think of the figure which follows; for in these cases, three short poles, united by an



iron bolt at top, with a spike in the lower end of each to take hold of the ground, are found the most convenient apparatus from which to suspend the beam.

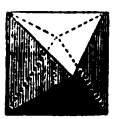
Now it so happens that there is not really, in any one of these cases, any single straight-lined triangle at all. The sailor's triangle is three imaginary lines on the surface of the sea, all of which are portions of circles; and in the other two cases there is no triangle at all, except when the instrument is in use, and then there are four triangles—one on each of the three sides, and one between the three points on the ground.

But notwithstanding the vague and imperfect notions which the unscientific have on the subject of triangles, this is one of the most important of all subjects—so important as to form a separate branch of science, under the name of *Trigonometry*, or "the measuring of triangles." This branch of science is by no means a small one. The mere elements of the doctrine of triangles fill volumes; and if all that has been written on triangles were collected, it would, in quantity at least, stock a large library. Nor is the quality less valuable than the quantity is great; for, excepting the mere length of straight lines, almost all that we know about the shape and magnitude of substances is known by means of triangles, and can be known in no other way. We cannot make a square figure, so as to be certain that it is square, without having recourse to triangles. We cannot make a plan of a house, or of anything else, without being indebted to triangles. We cannot measure the smallest paddock of land, or form an oval clump in a garden, without triangles. We cannot survey

a kingdom, a county, or even an estate, without triangles. We must have recourse to triangles in laying out our streets and roads. We cannot navigate the sea without them; and it is by means of triangles that we determine the figure and magnitude of the earth, and the distance of the sun and of other heavenly bodies.

And the fact holds good in nature as well as in our knowledge of extended matter. The masses of the universe—the sun, the planets, the moons of our system—all the independent bodies which are at great distances from us and from each other, are globes, or at all events nearly of the globular form; but, in the simplest elemental working of nature—that part of it in which there is neither organization nor life—there is good reason to believe that the primary forms are always composed of, or resolvable into, triangles. Four atoms placed thus, with three for the base, and one on the top, form the simplest elementary solid.

The material (called by chemists *carbon*) of which the diamond is composed, when combined in certain proportions with the elements of water and some other ingredients, forms chalk, lime-stone, marble, and many other earthy substances. It constitutes the basis of almost every variety of vegetable as it does also of many parts of animals. Mixed with that element, a constituent part of the atmosphere, which is life to us in breathing, it operates as a narcotic poison; whilst it converts some poisons into wholesome medicines. In its pure state it forms crystals of the following shape, which are the most brilliant, the most costly, and the hardest substances with which we are acquainted.



The black lines show the edges on the front side, and the dotted lines those on the other side, as they would appear if the transparent crystal were held up a little lower than the eye. The points are all alike, and so are the faces, which are triangles having three equal sides. Indeed the crystal may be split in the direction

of the faces till the piece becomes too minute for observation. Some of the most ingenious inquirers on the subject give it as their opinion, that the first formation of every crystal, whatever be the nature of its elements, or its ultimate form, is that of four little balls, three laid touching, and one on the middle, which figure, taken from centre to centre of the three balls, is an equal-sided triangle, and is the primary form into which space can be divided with the greatest economy. The cell of the bee, which is often referred to in illustration of this subject, is a combination of those figures; and the sphere itself may be regarded as a countless multitude of them. Here it is worthy of remark, that the very first problem in *Euclid's Elements*, without the help of which no one geometrical truth can be proved in a satisfactory manner, is the making of a triangle with three equal sides, the very form which we find in the fundamental crystals; and that this triangle is made by the help of the circle, which is the boundary or circumference of the sphere.

Section IV. Some Properties of Triangles.

The last-mentioned properties of the triangle, singular as they are, and little as he who glances at the figure as a mere shape of surface, and passes on to something which he hopes will be more gratifying to his restless but undirected curiosity, would be led to suspect their existence, are yet rather properties of triangular combination than of the simple triangle itself. Indeed, the triangle itself is not anything that exists; it is merely a relation of three straight lines to one another; and when that relation is, by any means, destroyed, there is an end of the triangle, though the surface on which it appeared, and the lines in their individual lengths, may remain just the same as before.

All science is, in truth, nothing but the knowledge of relations; for of things themselves we know nothing more than the effect which they have upon our organs of sense, and this is never any more than a momentary feeling of

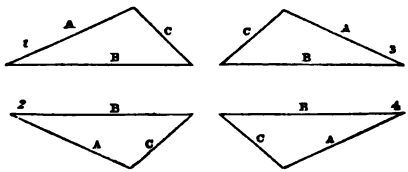
pleasure or pain, if indeed it be as much. We need not, therefore, wonder that they who do not reflect on what they see, and compare it with other appearances, and also its own differences of appearance with each other, are unable to inform us any further about anything than to name it when they see it, or point to it when they hear its name. This is all they can do upon any subject, be that subject what it may; and if the world had been all along peopled with such persons as they are, it would never have advanced one tittle in knowledge.

But let us look back at the triangle, not with a view to explain the science of triangles, which, like all elementary sciences, is rather dry to those who do not study it as an instrument by means of which they may do something else, but because it is, perhaps, the simplest subject of which anything like a scientific view can be taken; and yet there are points in the knowledge of it which have not yet been, and possibly never will be, determined.

First, then, a triangle is three lines so related to each other that each end of every line touches or meets one end of each of the other two. Could *any* three lines have that relation to each other?

Could we form a triangle of three lines which were seven, four, and two inches long, respectively? Let us see:—place one end of four to one end of seven, and one end of two to the other end of seven, will the remaining ends of four and two meet? No:—they want one inch, for their joint lengths are but six inches, and their other extremities are seven inches apart, taken on the line seven, which is the shortest distance. Now it is not because these lines are of the particular lengths that have been mentioned that they cannot form the triangle; but because one of them is longer than the other two. If two were just equal to the third one, there could still be no triangle, because then the two would fall just upon the third line, and the three would be all in the same direction. Hence we have one general property of triangles, namely, that any two sides must be together greater than the third side.

Secondly:—Can there be two triangles of different shapes made with the same three lines? No:—there cannot; though the one triangle may be put in many positions.



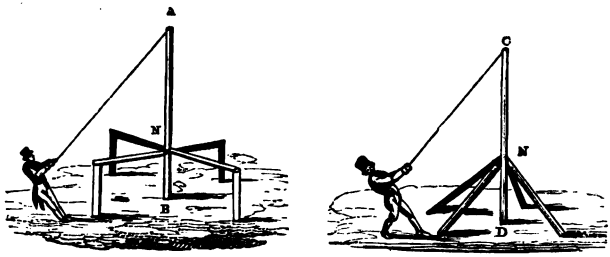
Let A B and C be the lines; the triangle may have any of the positions, 1, 2, 3, 4; but 2 is merely 1 turned over, and 3 and 4 are 1 and 2 turned end for end.

It is the property of having always the same shape when the sides are of the same length, which gives to the triangle a perfect stiffness or rigidity, which no other figure can possess; and also renders its properties more determinate than those of any other figure of which we know only the number and length of the sides. If we have the lengths of the sides, we can always find out everything else about the triangle, which is the case with no other figure; and if it be made of matter, though we may break it, we cannot bend it out of shape without bending the sides. On this principle it is that a gate with two pieces crossing each other from corner to corner is far stiffer than one with double the material in upright or horizontal bars, or than with two bars, the one across and the other horizontal.

Diagonal or angular pieces, called braces by the workmen, are of great service in carpentry, as they give stiffness, and also save materials.

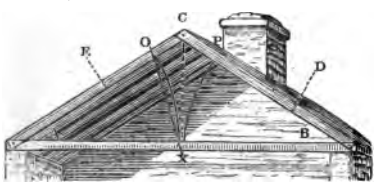
Thus, if a post, A B (p. 14) be "stayed," or supported by four horizontal pieces from the tops of four shorter posts which stand upright, more timber will be required than for a post C D, with four slanting braces reaching to the same height; and if each post be strained, as by a

man pulling a rope fastened to the top of it, the joints at the tops of the short posts to A B will work and loosen,



and the strain will be on the whole length of the main post A B; whereas, in the post C D, the strain will be only on the part C N; and if N be one-third of the entire length of the post from the ground, the post C D will bear the strain one-half better than the post A B.

The trusses of roofs are made upon similar principles. If flat and of considerable size, the roof would be apt to get hollow in the middle, and the rain-water would settle there and soon destroy it. But the common roof is made as follows:

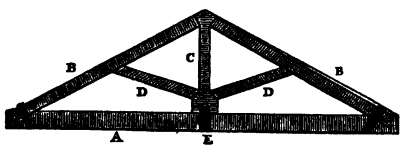


Trusses, composed of rafters A C and B C, jointed at the ridge C, and a tie-beam or girder, A B, uniting the lower ends of the rafters, are placed on the tops of the walls, as seen in the figure, and there support the roof, so that the girder not only carries nothing except its own weight, but it is strained tight by the pressure outwards in the direction of the rafters.

But though the action of the weight of the roof is thus thrown in the directions C D, C E, and would push the walls outward, if it were not that the rafters are tied together by the girder, that tie makes the roof press

downward on the walls. The rafters do not bear a weight equal to that on their whole length, but one equal to A X or B X, half the width or span of the roof, upon each; and if two portions A O and B P, each equal to half the span, are marked off from A C and B C, the remainders, O, C, P, will together express the strain on the girder. From this it is evident that when the pitch of the roof is high in proportion to the span, the cross strain on the rafters must be less, but it increases as the pitch is lower.

When the span is great, other pieces are introduced into the truss; but still the stiffness of the triangle is the principle of firmness. The following figure represents a simple but strong roof of this sort:



A is the girder; B B the rafters; C the king-post, which hangs by a wedge-shaped head from the rafters, and has the girder fastened to it by an iron strap at E; and D D are struts abutting on the heel of the king-post, and supporting the rafters at their centres.

The weight of the roof is on the walls as in the other case, and it is divided into a pressure on the rafters and a strain on the girder; but as the struts support the rafters at the middle, the pressure on the rafters is divided, and part of it thrown upon the struts, as a thrust, and another part on the king-post, as a strain.

In the language of carpentry, pressure on the side of a piece of timber is called a weight, a load, or a cross strain; on the end, it is a thrust or crush, and if it be a pull at each end, it is a strain. That which is loaded is a beam; that which is thrust, a strut; and that which is strained, a tie.

What has been mentioned will show how very necessary it is to be acquainted with the properties of triangles.

Section V. A Watch.

The instance of the triangle will show how differently it stands with those who have a scientific habit, and those who have not, in a simple case, where the original principles are few, and belong to one subject. In the triangle, there is really nothing but the three sides and the three angles, and their relations to one another and to other lines and figures; and yet the triangle is not only a subject which requires much, and in many instances severe study, but we must take it along with us as an instrument, without which we cannot obtain much of the most necessary knowledge either of nature or of art. Let us take another example—that of a common pocket-watch.

Well, suppose a native of some country in which nothing was known but the spontaneous fruits of the earth, to be cast upon the shore of England, where all things were new to him, where he had as yet seen no people, and nothing of human art; and that he spied a watch suspended from the bough of a tree, upon which there were plenty of leaves, different in character from any leaves he had seen, but neither flowers nor fruit: what would be his first impression about the watch? Assuredly, he would consider it part of the tree; but whether flower, fruit, or some excrescence, would depend very much on the characters of the trees with which he had previously been conversant. As people not at the very bottom of the scale have, before now, mistaken a dragoon for part of a horse, and a military hat for part of a man's head, it is no stretch of fancy to suppose that one at the very bottom of the scale would mistake the watch for a fruit. No question of it; for there was a period in each of their lives, when Graham, or Le Roy, or Arnold, or any of the most enthusiastic and successful watch-makers that ever lived, would have conveyed the choicest production of his predecessors to his mouth as readily as any article of food. The savage has more experience in the process of eating than a child; and as necessity forces him to many shifts

that are not required in a civilized country, it is probable that he might be sharper in finding out edible qualities, and the reverse, than those among us who make that their study. Still, he would have no more knowledge of the use of a watch; and to him it would not so readily occur that the watch would let him know how time passed, as that it might probably satisfy his hunger.

There are many stories told of people, who, from the motion of the hands, and the ticking, have concluded that watches were living creatures, and that when they ran down, and their motion ceased, they died. There is even one story of a man, and he not some wild man of distant places, but a shrewd Scotch Highlander, who had got so much attached to a watch during the short time that it had *lived* in his possession, that he was preparing to bury it; when one better acquainted with it came in accidentally, and rescued it from the earth. The hut was set out as for a wake, after the fashion of the then days in that part of the country; and Donald wore not the mere semblance but the reality of sorrow. His acquaintance asked what was the matter; and the response was, "She died last night; and as she was a cantie wee clatterin creature when leivin', nainsell's just to gie her a bit decent burial."

To the inhabitants of crowded and bustling places, whose lives are mere successions of sensations, and to whom perfectly original thought is almost as great a novelty as the watch was to the Highlander, these stories may appear both trifling and incredible; but such persons little know to what absurd vagaries the mind can be driven when it must think, and there is neither subject nor guide. Strange as it may seem, the beginnings of wisdom often lie in these apparent fallacies; and where there are not the opportunities, thinking wrong is a ground of hope, as compared with indifference and want of thought, where the opportunities exist. A callous and indifferent population in crowded cities, is far worse, every way, than a dreamy and superstitious one scattered over the wilds.

In England, there are probably few persons who do not know the use of a watch, and that it has value as a marketable commodity; but there are many who cannot tell the hour by a watch; and of those who can do so with one that has a plain dial, there are not a few to whom a second's hand is a great puzzle.

But the very ignorant are not the only persons who have not what may be called the science of watches; and so the fair contrast is not between them and those who have that science. Suppose we take an ordinary watch-wearer—one who knows the hours, minutes, and seconds; can wind-up a watch, and bring it to time by the common regulator. This forms the whole, or at least the greater part, of what ordinary people know about a watch; excepting the appearance, price, fashion, materials, and other conditions, which have none of the peculiar science of the watch in them, but are common to all articles. There are many persons who have knowledge of a watch thus far, who have worn one for years, and would feel very uncomfortable without it, and who yet would be a little puzzled if one were to ask them the source of motion in the watch. The balance would first occur to many, because the motion of that is most rapid, as well as best seen; and if you pressed them for a reason, they would in all probability say (as has been said to the author when he put the question), that "the balance swings one way *of its own accord*, and the balance-spring (which is coiled about the arbor of the verge) brings it back the other way." If you rejoined, "How of its own accord?" your catechumen would probably begin to talk about "perpetual motion," or anything, in short, to conceal his ignorance; for where ignorance is total, all words are equally applicable.

In general, however, the knowledge may be supposed to extend a little further than this, though it is really astonishing how ignorant even well-educated and sensible people appear on many of the little every-day points of mechanical science, when you question them closely, and

they are willing to answer you readily and fully. The especial wonder of the matter is, that the man will often know "by book," all the principles, both mechanical and chemical, upon which a watch of the most perfect and valuable kind is constructed, and yet not be able to point out or comprehend one of the applications of those principles in the watch itself.

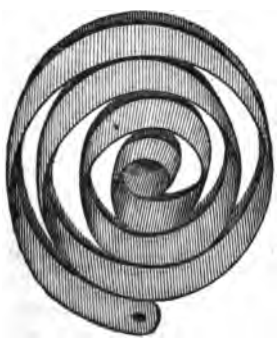
Strange as this may seem, it is, nevertheless, quite true. I was intimate with a very well-informed and most successful teacher of mathematical science, and indeed of science generally, who is still alive, a professor in a university, and one of its most valuable and efficient members; and I used sometimes to amuse myself at his utter perplexity with the application of those principles, the theory of which he understood so much better than I could pretend to. But, as many of his pupils could prove, if it were proper to put them in the witness-box, his instructions lacked nothing upon that account; for though he himself could not have engineered a mouse-trap, others have become very clever and valuable engineers from his instructions; and once, when I was expressing some wonder at an improvement in machinery made by a very young man, I asked him how he came by it, and the answer was "In Mr. ——'s class."

In some cases, it is probably as beneficial to have a division of thought, as it is to have a division of labour, and a distinction of ranks in society. It may be that the man who merely notices a watch, without attending to the principles upon which it is constructed, may know that there is no *power* of motion in the watch itself; that the friction of the movement consumes no inconsiderable part of the power which is communicated to it in the winding-up; and that the motion of the hand in turning the key some nine or ten revolutions, not only overcomes all the friction of the movement, but carries the hour-hand twice, the minute-hand twenty-four times, and the seconds'-hand one thousand four hundred and forty times, round the dial—while so nicely

formed is the whole machinery, that the power which thus divides and subdivides the twenty-four hours, so that the owner of the watch may keep his appointments to a second, is so small, that the most delicate lady barely feels it as a resistance to her finger. When one arrives at this degree of knowledge, however, the probability is, that the desire of the science will be excited, and the party will wish to inform himself about

SECTION VI. THE STRUCTURE OF A WATCH.

THE best iron ore is found in little masses, having some resemblance to kidneys both in shape and colour; and if one were to bid a person unacquainted with science, and with those arts of which science is the foundation, take one of these little lumps of compact and heavy stony matter, and so prepare and fashion it as that it should be a certain means of letting him know the hours, he would deem it an impossibility. Yet that same substance is made into cast iron by one process, into malleable iron by another, and into steel by a third; and the steel being made into a long narrow strip or ribbon, something like the following figure, and tempered in the proper manner, becomes the spring which gives motion to the watch, or rather, which distributes uniformly over the whole twenty-four hours that portion of original motion which is given by the hand in winding-up the watch.



The long strip of tempered steel just described is called the *main-spring*, and is inclosed in a cylindrical box, or barrel, which turns upon a fixed axis. One end of the

spring is made fast to this axis, and a little button at the other end fits into a hole in the barrel; one end of the spring is therefore fast, and the other is moveable, but moves the barrel along with it.

The action of the main-spring depends on its tendency to uncoil, and the power it exerts is communicated to the other parts of the watch by means of a very fine steel *chain*, the peculiar construction of which is shown in the following figure. It consists of two plates laid over each other, the ends of each pair being connected with those of the next pair, by a single plate of the same form and size placed between them and fastened by a rivet passing through the three. By this arrangement the chain is flexible only in two directions, and not in all directions, as common chains are.

The watch-chain has one end fastened to the barrel containing the spring, and the other to the fusee, or spindle of the watch, the bottom of which moves a wheel, which puts the whole train, or wheel-work of the watch, in motion.

The fusee has a spiral groove winding round it, into which the chain coils; and one end of the fusee is much thicker than the other, and it diminishes in a curve, for reasons to be explained presently. The fusee is something of the following shape.

The fusee and wheel are not fixed together, although, when the watch is going, they turn round in the same direction and at the same rate. The fusee is fixed to the arbor or axis, and the wheel is merely fitted to it, and hollowed out on its upper surface, so as to receive the lower or broad end of the fusee. That end has ratchet, or saw-like teeth; and the wheel has a little catch, which is pressed into the teeth of the ratchet by a spring; so that the fusee can

move without the wheel in the direction opposite to that in which the watch goes, but not in the same direction. If this were not the case, the watch could not be wound up, and so would not go at all.

The following figure will show the manner in which the fusee turns one way without moving the wheel, and when required moves the wheel the other way.

The external circle represents the toothed wheel which moves the train of the watch, and turns freely on the arbor of the fusee. The second circle is the flanch within which the wheel is hollowed so as to receive the ratchet wheel of the fusee. The third circle is the ratchet, between which and the flanch there is a catch, pressed against one of the ratchet-teeth, by its spring.

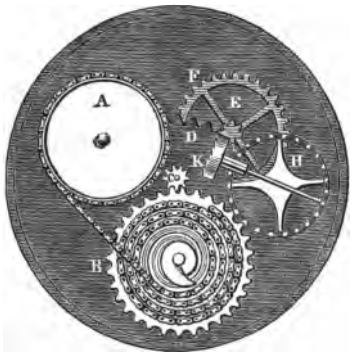
The chain moves the fusee in the direction in which the catch stops the teeth, so that the fusee carries the wheel along with it. But when the watch-key is placed on the square, and the fusee forced round, the sloping side of the ratchet-tooth presses the catch against the spring, so that the tooth passes, and so do all the other teeth in succession, with only a little clicking noise of the catch caused by the recoil of the spring. The parts are so formed, too, that the resistance of the spring is more toward the centre of the motion than against its direction, and thus the wheel does not strain the movement of the watch.

Common watches stop while winding-up, as there is nothing in them to move the wheel but the fusee; but in watches of better construction, there is a spring, called a maintaining power, which is bent by the action of the fusee and the resistance of the wheel upon ordinary occasions; but which, when the pressure of the fusee is taken off, by the operation of winding, continues the motion of the wheel, so that the watch does not lose time in winding, as is the case with common watches.

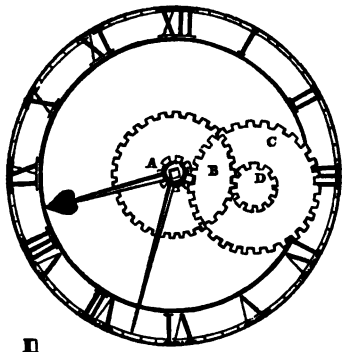
The arbor, or axis on which the spring-barrel turns, is the fulcrum or point of rest in the watch; the spring is the immediate mover; and the fusee, with its wheel, the first part of the moving train. That train is carried up by large wheels moving smaller ones, which are called pinions, till the balance be arrived at, which is the last and most rapid part of the moving train, and regulates the motion of the whole.

It is not necessary particularly to describe the wheels, as our object is to explain merely the principles of the watch; and the arrangement of the wheels, as well as the number of teeth in them, admits of variety. The object of the whole is to bring up the slow motion of the fusee, so that each beat of the balance may be a second, or some number of beats equal to a known number of seconds.

The following is, however, a representation of the machinery of a common vertical watch, so far as it can easily be shown in a figure.



A the spring barrel; B the fusee, chain, and first or fusee wheel; C the centre pinion moved by the fusee wheel; D the centre wheel, which revolves in an hour, and moves E the pinion of the third wheel F. F moves the concealed pinion of H the contrate wheel (so called because the teeth are at right angles to the plane of the wheel); H moves the pinion I of the 'scapement-wheel K, and the ratchet-teeth of that move the pallets of the verge, which recoil by the reaction of the balance-spring.



The arbor of the centre wheel carries the minute-hand; and that of the contrate wheel the second's-hand, when there is one.

The pinion A fits on the centre arbor, thus—

It revolves in an hour, and carries the minute-hand. It moves the wheel C, carrying the pinion D, and D moves B, which carries the hour-hand, revolving once in 12 hours.

The socket of A, which connects the dial motion with the rest of the train, is not fixed to the centre arbor, but fits it tightly, yet allowing the hands to be set to time without disturbing the train.

Section VII. Motion of a Watch.

Let us suppose that the watch is 'in going order;' but that it has 'run down,' and stopped. In that case, the chain will be coiled round the spring-barrel, and there will be no more on the fusee than that which is prevented from getting off by 'the stop.' The spring will then be as 'wide' in the barrel, that is, it will have as few turns round the fixed axis as possible; but still it must be held to a considerable extent by the chain, otherwise the last motion of the watch would be irregular.

Upon applying the watch-key to the square on the arbor of the fusee, and turning it round, the chain winds upon the fusee from the barrel, and the catch makes a clicking noise as the teeth of the ratchet-wheel on the bottom of the fusee pass it; but that catch gives way so

easily in the direction of the winding, that the wheel, or any part of the train of the watch, is not in the least disturbed. If we should attempt to force the motion the other way, the watch would move faster than its natural rate, and even be strained and broken. As the chain is coiled on the fusee, and off the barrel, the spring is once coiled round the fixed axis of the barrel for every turn of the chain that is drawn off; and it is this coiling up of the spring which is the power given to the watch in the winding-up; because the spring, by its elasticity, re-acts, or comes again out of the close coils into larger ones.

The force required to coil up the spring, and the force with which it re-acts, are variable, but they both vary at the same rate. The looser the spring is, the smaller the power required to coil it, and it re-acts with the less force. If the fusee were everywhere of the same diameter or thickness, as well as the spring-barrel, the last turns of the winding would require more force than the first; and the power of motion in the watch would gradually become less and less from the time of winding-up till it required winding again. Such a watch would not measure time equally, as, although it were regulated for the whole twenty-four hours, it would not make all the hours of equal length. For a reason that will appear when we come to treat of the balance, it would go faster as the power of the spring became weaker.

To counteract this, the lower part of the fusee—that which answers to the state of feeblest re-action in the spring—is made broadest, and the fusee is tapered in a curve to its other termination. The exact taper, to render the power perfectly uniform, is too nice for being calculated; but the watchmakers adjust it by trials; and as no two springs coil up exactly the same, every time a watch gets a new spring, the fusee requires to be adjusted to it.

A hand which has been educated to measure pressures very nicely, can judge, in winding a watch, whether the fusee and spring are very much out of adjustment. If

so, the weak parts of the spring will be more easy to coil than the strong parts. One can easily understand the reason. The barrel being a perfect cylinder, always exerts the same lever in pulling the chain off the fusee; but the power which the spring exerts constantly diminishes, and, therefore, the whole power to move the fusee, and by that the train of the watch, constantly diminishes. But a diminished power, acting on a longer lever, continues to produce the same effect; and as the radius, or half-diameter of the fusee, is the lever on which the spring and barrel act to move the train of the watch, and as that increases in the same proportion as the power of the spring diminishes, the impulse given to the train is, in a well-made watch, the same during the whole period of its going.

The larger the barrel is, the power of the same spring is the less; and the larger the fusee is, it is the greater. So that, besides the adjustment of the fusee in shape, for the purpose of obtaining uniform force and motion, there is a general adjustment of the calibre of the one to that of the other, so that the impulse given to the train may neither be too small nor too great. If it were too small, the watch would be apt to stop from the most trifling causes; and if it were too great, the fast-moving parts would be worn or strained; and, in either case, the value of the watch would be lessened.

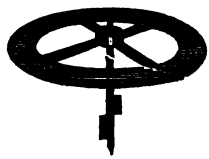
Much, also, depends on the accuracy and polish of the working parts of the train. The wheels and pinions should be perfectly true; their axles or arbors should be exactly parallel, and the pivots should turn with the least possible friction, but without any play in the holes. Small teeth and high numbers, both in the wheels and the pinions, contribute much to the regularity of the motion; and if a watch has not these, there is seldom much laid out in the finishing of it.

As the power communicated by coiling the spring, in winding-up, is confined to the fusee and the spring-barrel, comparatively little of it is lost by the friction of the

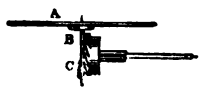
machinery; but when that power re-acts upon the train, so that each part in general moves the next part faster than it is moved itself, there is, at every movement, independently of friction, a loss of power proportional to the increase of speed. Hence the power of motion in the last, or fastest part of the train, is only a very small fraction of that in the first; and as that is very small in itself, being perhaps not much more than the action of a pound or two for a minute extended over about thirty hours, we need not be at all surprised at the small obstacle which, applied to the quick parts of the train, will stop a watch. Numerous as are the parts of the movement, however, and small as is the power, if there were nothing but the spring, the fusée, and the train, the watch would be of no use, as it would run down in a very short time, and the more nicely it were made, it would run down the faster. This is prevented by the balance, which, even in its most simple form, is a very ingenious contrivance, as, by repeated short interruptions, it retards the motion of the balance-wheel, by which it is impelled.

Section VIII. Watch Balance.

The common balance-wheel, which is called the ''scapement'-wheel, because of its teeth escaping in succession from the 'pallets,' or little projecting pieces on the 'verge' or arbor of the balance, is toothed in the saw form; and as it stands upright, is called the 'vertical' 'scapement. The balance is a flat thin wheel of steel or other metal, having the verge or axis perfectly true, and the pallets forming an angle with each other something like the following figure. The balance would be of no use but for the balance-spring, which has one end fastened to the arbor of the balance, and the other to the frame of the watch, while a number of coils of the spring surround the arbor as here shown.



A tooth of the balance-wheel bears upon one of the pallets; and the impulse communicated from the main-spring through the train to that tooth, presses on the pallet, and turns the balance round till that tooth 'escapes.' The balance-spring has, however, been bent by the turning of the balance; so that the instant the tooth escapes, the spring brings round the balance in the opposite direction, and the other pallet catches a second tooth of the balance-wheel, and opposes its motion by the recoil of the balance and the force of the spring. The collision of the pallet and tooth is one beat or tick of the watch; and were the resistance of the pallet to continue greater than the moving force of the wheel, it would stop the watch.



The annexed is a profile of the 'scapement—A, the balance, B, the stopping pallet, C, the pallet to stop the next beat.

But the stroke of the pallet is merely momentary, and so the very instant that it strikes, the tooth begins to push it round, and bend the spring, till that tooth escapes, and the other pallet catches another tooth in a second beat. The watch goes on in this manner as long as the train is in order, and it is kept wound up. The further the balance swings, the more firm and regular are the beats, and the watch keeps the more equal time.

The more elastic the balance-spring is, the further the balance vibrates, the more forcibly the pallets meet the teeth of the wheel, and consequently the motion is the slower, as well as the more uniform. The weightier the balance is, so that its friction is not thereby increased, the better; as the force with which it strikes the beat is compounded of its own weight and the reaction of the spring. The regulator of a common watch shortens the balance-spring, by which the watch is made to go faster, and lengthens that spring when the watch is required to go slower; and within narrow limits, these changes in the length of the spring do not very materially affect the regularity with which the watch goes.

Section IX. Principles of the Watch.

The properties which have been noticed are those of the most plain and common watch that is made; and yet, when we come to consider them, the bringing into combination of all the principles which they embody is astonishing. This must strike any one who considers the smallness of the entire movement; the adjustment of the size and strength of the parts to the strain that is on them, so that the whole may be equally strong, and no part loaded with unnecessary weight; and the adapting of the elasticity of the spring, the size of the spring-barrel, and the diameter of the fusee, to each other, so that there shall be sufficient force to keep the watch going, and yet not so much as to strain the machinery. These last adaptations must all be made with reference to the balance; and to that again the teeth of the balance-wheel and the pallets and spring must be so adjusted, that the vibrations of the balance may be as wide as possible, and perfectly easy, and yet that the beats may not be such as to cut the pallets. As so very nice a piece of machinery requires to be kept carefully clean, it is necessary that the whole should be made to come to pieces and put together again, not only without injury to any of the parts, but without much ingenuity or skill. Then, in a machine of which the materials form so small, and the workmanship so large, a portion of the value, it is desirable that the whole and each part should be as durable as possible. The choice of the materials contributes a good deal to that purpose; and as it has been found that brass and steel are not only the best of cheap substances for fine work, but move upon each other with the least friction, they are selected for the working parts of the watch. Harder substances, as ruby and diamond, are sometimes introduced for particular parts; but only in very highly-finished movements.

The strain upon the watch is so little, that if it be kept properly clean, the only parts subject to wear are the pallets and balance-wheel; and though the wheel is brass

and the pallets are hardened steel, it is the wheel that wears the pallets, and not the pallets that wear the wheel. The reason of that will at once appear, when we consider, that if there be thirty teeth in the wheel, each pallet will be met thirty times for once that the same tooth is met. Thus, though the wheel would suffer most from one hard blow—as a steel hammer will dent brass, while brass, at any ordinary rate of motion, will not dent a steel hammer, —the repetition of thirty little blows for one multiplies the action of the brass, so as to make it greater than that of the steel.

It is worthy of remark, as a general principle, that small impulses, if repeated often enough, will overcome great resistances. Thus, the light gravel which rivers wash down, and even the water itself, cuts channels in the hardest rocks; and the palm of the hand polishes wood and brass, and even steel, in an article that is much used. Rapidity of motion produces effects similar to those of frequency of action. With a sufficient charge of gunpowder, a tallow candle may be shot through a thick deal board; the wind can overturn a house, or uproot a tree; and if sufficient motion could be given to air, there is no doubt that it would cut or engrave steel or a diamond. The motion of the watch-balance is, however, comparatively slow, and the force small, so that, if the construction and polish are at all good, the pallets will last many years without cutting.

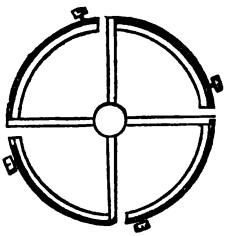
Section X. Watch Balances—Chronometers.

Nice as those adaptations are, and many as are the applications of science required for producing a good watch of the common construction, such as has been explained, they are not the most scientific parts of the business. It has been mentioned that the beats or vibrations of the balance are more uniform, the further the balance swings, and the more elastic the balance-spring. To accomplish these purposes, various 'scapements have been contrived by ingenious

men, and in some of these the working parts are so nicely adjusted, and the balance-spring formed into so many coils, and so elastic, that the balance swings a full revolution quite free or 'detached' from the wheel. A good balance of that kind is a very superior piece of art, the balance-spring especially. As that spring is coiled up spirally, the coils increasing to the outside, it is evident, that if the spring were all of an equal thickness, the small coils would be much stiffer than the large ones, and only part of the spring would act. The equal action of the whole spring is the object; and so it is tapered down towards the balance end; and as the rate of that taper is too fine for being calculated, or set off by any instrument, it requires a very neat-handed and experienced workman. Mr. DENT has lately made balance-springs of glass, which are exempt from expansion, rust, and magnetic influence.

Such a spring would have its perfection injured, if it were lengthened or shortened by a regulator for bringing the watch to time, as is the case with the common balance. The newly-invented balance is brought to time by means of fine screws, with pretty large heads, in the circumference. Screwing these outward extends the balance, makes it vibrate wider, and the watch go slower; and screwing them inwards has the contrary effect. This is in many respects better than the regulator acting in lengthening or shortening the spring. The spring, the elasticity of which has the principal effect in stopping the wheel by the beat, acts uniformly in all states of the 'mean-time' screws; and the screws admit of a much nicer adjustment than any regulator, as they can, by a delicate hand, be touched to the two-thousandth part of an inch, which will not make an alteration of one-twenty-thousandth part of each beat, or indeed half that quantity. Five beats in two seconds is the common train of such watches, when made for wearing in the pocket; and thus we may say that the movement can be adjusted to less than the hundred-thousandth part of a second, with more certainty than a common watch could be to the tenth of a second.

This may be regarded as about the ultimate degree of perfection in the watch, as depending on the principles of purely mechanical science, that is, on the forms of the working parts and the elasticity of springs; but when that degree of perfection and delicacy has been arrived at, new sources of error are discovered, which must be corrected by other contrivances. All substances expand, or are enlarged, by heat, and contract, or are diminished, by cold; so that a watch nicely regulated for the climate of England would go too slow if carried to the warm countries, and too fast, if carried to the cold. Different substances expand and contract to different extents with the same degree of heat; and thus the balance is cut into segments, and the parts made up of one piece of steel and another of brass, the different expansions and contractions of which exactly counterbalance or compensate each other. Hence, within all ranges of heat that are likely to occur, from any change of place and of weather, the balance remains the same, and the rate of the watch is uniform. These are called 'compensation balances:' and that in the margin is one of the forms.



Watches having such balances, with proper balance-springs and 'scapements, are called *Chronometers*, or 'Time-measurers;' because they can be depended on as dividing or measuring time into equal parts. The time which they keep is the nearest approach that can be made to equal hours in absolute duration; and thus they are said to keep 'mean time,' as distinguished from 'apparent time,' shown by the sun, which, in consequence of the variations in the sun's apparent motion, is sometimes faster than mean time, and sometimes slower.

These chronometers, besides their beauty, and the great ingenuity displayed in the construction of them, are instruments of very great value, not only for the accuracy with which, by means of them, time may be kept on land,

but for the important service they render to navigation. By means of his chronometer, the mariner can carry Greenwich time with him round the globe. On ascertaining, by astronomical observations, the time where he is, and converting the difference between that and Greenwich time into degrees and minutes, at the rate of four minutes in time to a degree of longitude, he can determine the longitude, and know where he is with very little labour; not only making sure of his way across the pathless bosom of the ocean, but arriving at his appointed port by the shortest course, safe from the dangers of rocks, currents, and opposing shores. The watch has thus saved from destruction much valuable property and many lives; facilitated the intercourse of nations, and brought the ends of the earth nearer each other for all useful purposes; and the watch is only one among many thousand of equally valuable applications of skill and the knowledge of science.

Let it be remembered, that the only test of excellence in time-measurers, whether clocks, watches, or chronometers, is, that the going-rate be constant, that is, whatever be the actual amount of error in any given period, whether 'fast' or 'slow,' it must always be uniform, and in the same direction. If clocks and watches, in ordinary use, were submitted to this kind of trial, only a very small number would pass their examination with credit to themselves, or their makers. In the common business of life, and with the means of frequent comparison and correction so easily accessible, extreme accuracy is not essential; and, at the prices charged for the greatest proportion of clocks and watches, it is not attainable.

Watches which are carried about the person are generally more variable than clocks; being affected by the motions of the wearer, and by the changes of position, and of temperature during the night. It is by no means unusual for a watch to have a losing-rate by day and a gaining-rate at night; and yet, by numerous adjustments, these errors, in opposite directions, may be made so nearly

to compensate each other, that the mean rate obtains for the watch a character for 'going well.' Such going well may do on land, where a few seconds 'fast' one day, and 'slow' another, is of no great importance; but it would never do at sea. Chronometers intended for the purposes of navigation are subjected to a series of trials, and experiments, and observations, which embrace every conceivable kind of motion and change of position, and also extreme ranges of temperature, and variations of climate. The observations extend over many months; and although it is too much to expect that any work of man's hands should be absolutely perfect, yet is perfection in mechanically dividing and measuring time so nearly attained, that very recently a chronometer which had been exposed to the cold of a Polar winter, had, during seventeen months, undergone a change in its daily rate of only the three-hundredth part of one second.

Section XI. General Relations of Light, Heat, Electricity, and Magnetism.

Light and Heat are among the most interesting subjects of human knowledge. Light is the means by which the whole visible creation is revealed to us; and there is no operation, either natural or artificial, in the performing of which heat is not in some way concerned.

A knowledge of the most ordinary properties of heat is so important for every one who wishes to understand science in such a way as that it may be useful, that an instance or two may be mentioned. Common fire is a principle with the action of which everybody is familiar; and whatever may be the fuel with which it is fed, whether common pit-coal, or wood, or turf, or anything else, we always consider the fire, that which burns the fuel, as being the same. We do so without any regard to the means by which it may be at first kindled. We may obtain it by a brand or a burning coal from a fire already kindled, by striking a piece of steel rapidly with a piece

of flint and catching the sparks on dry tinder, by igniting by friction a chemically prepared match, by hammering iron on an anvil, by rubbing one piece of dry wood against another, and by various other means; and a fire may be kindled naturally by lightning, and by various actions of moist bodies, such as wet hay or other vegetables, and sulphur and iron filings moistened and covered up from the air; and also by the friction or rubbing of very dry bodies against each other; in which way the dry reeds and forests of tropical countries are often set in a blaze.

But, in what way soever we obtain it, we always consider it as being the very same fire; and we are right in so doing, and should be wrong if we did otherwise. Whatever may be its source, the same degree of it always produces similar effects on the same substance, if that substance be in the same state, and the fire applied to it in the same manner.

But this fire, which we must regard as being the same in all cases, as it has the qualities by which alone we can judge of sameness in anything, acts differently on different substances. Put a piece of pure clay in the fire, and it will remain unaltered, except in size. Sprinkle water on the fire, and it will rise up in steam with a hissing noise; or, if the quantity be great enough, it will carry up all the fire with it, and the fuel will be extinguished. A piece of fat will soften and melt, but an egg will become hard, though in the end both will be burnt. The same fire, too, which roasts an apple till it is soft and moist, roasts a potato till it is dry and mealy. In all these, and in many other instances which could be mentioned, the difference of effect is in the substance, and not in the principle; and therefore, in order that the science or knowledge of any event that happens, be it what it may, may be useful, we must know the object acted upon as well as the agent that acts upon it.

Electricity is abundantly diffused throughout nature. Its effects are exhibited in a variety of ways, and its influ-

ence is probably as essential to the constitution of matter as that of light and heat. Until within the last few years electrical phenomena were but partially observed and imperfectly understood. Our knowledge of this important branch of science is now greatly extended, and is still rapidly advancing; that which was once a subject of conjecture or of vague speculation, being now verified by the most satisfactory experiments. We here allude to the identity of the principle of electricity, whatever may be the difference in its action; for it is perfectly consistent with our experience that the results of the same principle, acting in different ways, and on dissimilar substances, may be just as distinct as if there was a difference in the principles themselves. In treating of electricity, therefore, as a science, it is necessary to divide it into separate branches. Thus we have *Common Electricity*, which is produced by friction—*Voltaic Electricity*, called also *Galvanism*, which is the result of chemical action—*Magneto-Electricity*, or that produced by magnets—and *Thermo-Electricity*, which is developed by heat.

In proportion as facts illustrative of electrical phenomena have been multiplied, so have our views expanded respecting magnetism, in which almost everything that was known about thirty years ago, was the power possessed by an ore of iron to communicate permanent polarity, and an attractive and repulsive influence, to iron and steel bars. This property of the loadstone was known to the ancients, but there is no evidence that it was applied to the purposes of navigation until the beginning of the twelfth century. It is now very generally believed that electricity and magnetism differ only in their mode of operation, inasmuch that precisely the same effects may be produced by both. For these interesting discoveries we are indebted to an entirely new department of experimental research—namely, *Electro-Magnetism*.

But important as these principles are, and impossible as it is to have useful science in any matter unless we understand their modes of working, we are in utter ignorance

of the principles themselves, as no analysis, that is, no process of decomposition, or separation, with which we are acquainted, can obtain us any one of them in a separate state, so that we can examine it and say what it is. We cannot even say that they are material things at all, for they neither admit of being measured nor weighed. We are familiar with them only as *phenomena* or *appearances* of matter, and though in thought we generalize them, and in language express them by *nouns* or *names*, as if they were things having separate existences, yet we know them only as qualities of other substances, properties superadded to matter, and their names are in reality *adjectives*. Hence it is most rational to believe, that however we may designate Light, Heat, Electricity, and Magnetism, they are but different *modes* of *one* single energy.

Still, we are in no worse condition with regard to them than we are with regard to anything else; for all our knowledge is only the knowledge of qualities; and when we explain anything we merely mention all the qualities of it.

Section XII. General Appearances of Light.

Light is perhaps the most beautiful, and probably one of the most useful phenomena in the world. It is light which gives colour and displays form—at least form in all cases where we cannot touch the objects. When the day draws to a close, the differences of colour which make nature so beautiful during the bright sunshine, gradually lose their distinctions, and fade into one dull though soft gray, before the blackness of night comes upon them Even in our darkest nights there remains some trace of colour, though neither moon nor star appears; and unless they are both hidden by fog, we can always tell where the earth and sky meet at the horizon.

But when one is in a deep mine, where the light of day has never entered, more especially if it be a coal-mine, the interior of which would of course be black even in the light, the darkness is palpable, and to one who is there for the

first time and left in silence, with the lamps and candles extinguished, it is truly terrific. One feels as if pressed on all sides by the gloom, so that there is not only an interruption of motion, but breathing feels difficult, and all means of knowledge are suspended. If in such a situation one turns round, it is not possible to find again the direction of the mine; and if a retreat is attempted, one is just as apt to go further into the mine, or to turn into one of the "rooms," as to keep the gallery which leads to the entrance. After some time, in that darkness the dim light of a taper seems as radiant as the mid-day sun; and if one is led out thickly blindfolded, it is not easy to describe, or to imagine, if it has not been actually felt, how clear and beautiful all nature appears.

To open the curtains and shutters of a darkened room, and look out on a summer's morning, when one has just awoke, and the sun is newly-up, is a delightful sight—superior to any which the lingerer in bed can see; but even this is not to be compared to the return from the mine. Both are, however, beautiful displays of light, and calculated to impress us with a sense of the blessings which light, and those eyes by means of which we see it, are to us, and how grateful we ought to be for the enjoyment of them.

These instances show that it is the light which reveals the colours to us; and it is exceedingly probable that the light actually produces the colours; that is, the different states of the surface of bodies, which make them appear of one colour rather than another. As we never see the colours but by means of the light, we have no means of knowing whether, in all cases, bodies retain their power of showing the same colour when they are not exposed to the light; but we do know that in many instances of vegetables, the light does originally produce the colour. Plants that grow in the dark are white and sickly, or, as it is technically called, *etiolated;* and if green leaves and stems are covered with earth, they become white or blanched. This is not general, however, in the colours even of vege-

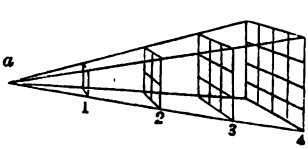
tables; for in some, as in the ash and the elder, we find the outer rind, or *epidermis*, pale coloured, while the inner bark is green; and in many trees—in the laburnum and pine, for instance—we find the wood near the surface white or pale, while that nearer the pith is much darker.

But whether the production of the kind of surface that shows one colour rather than another be occasioned by the substance itself, by the action of light, or (which is the most probable supposition) by the joint action of the two, it is established by the clearest proofs, that if the light does not contain that ingredient of its composition upon which the colour depends, that particular colour is not seen.

The particular composition of light we shall describe afterwards; but in the meantime we may remark, that if objects are looked at through a piece of glass or any other substance of a particular colour, they all appear tinted with that colour; and if any of the component colours of light be taken out of it by the substance through which it passes, or by any other means, the remainder of the light will not show the colour so taken out.

Section XIII. General Properties of Light.

Light is emitted, or given out, in all directions, from every point of the surface of luminous bodies, that is, of bodies which "shine of themselves;" and its progress through substances which are everywhere of the same density, is in straight lines. Thus, the quantity of direct light, from one luminous point, which falls upon the same extent of surface at different distances, is inversely as the squares of the distances. This may be simply, yet clearly illustrated by the annexed figure. Let A be a luminous point, from which the rays of light proceed in the direction of your right hand; and let 1, 2, 3, 4, be four square



pieces of card or any other opaque matter, placed respectively at the distances of 1, 2, 3, and 4; then, if all the cards have their centres in the same straight line, stand all in the same position, and are such that the shadow of the first obscures the second, the second the third, and the third the fourth, exactly, and no more, then the second will be four times, the third nine times, and the fourth sixteen times, the size of the first. If the series were carried on to a greater extent, still at the same distances from each other, the fifth would be twenty-five times, the sixth thirty-six times, and the seventh forty-nine times the size of the first; and to whatever number the series were extended, the surface of the card, or, which is the same thing, the section of the shadow of the card, at 1, would increase as the square of the distance.

The same truth may be illustrated by various other means. Thus, if a square hole be cut in an opaque substance, and that substance placed at any distance from a luminous point, and the pyramid of light, which passes through the hole, received upon a screen parallel to the opaque substance in which the hole is cut, the illuminated part of the screen will, at whatever distance it is placed, always be, to the size of the hole, directly as the square of its respective distance. Now it is quite evident, that, from the luminous point, there can fall no more light upon the screen than comes through the hole; and therefore, as the surfaces on which the same quantity of light falls are directly as the squares of their distances from the luminous point, the intensities, or quantities of light on equal surfaces must be inversely as the squares of the distances. Hence, in proportion as objects are removed from the source of light, the light which falls upon them must appear more and more dim.

This explains many of the phenomena of light which we observe in nature; but in applying the principle we must be upon our guard against errors not very dissimilar in kind to those into which some pretenders to science have fallen, in delivering their dicta on what is by them an

imperfectly understood law of the variations of gravity with changes of distance. In the case of gravitation, there is a point—a centre of gravitation—from which the measures of distance should be begun, and if the distances are taken from the surface of the masses, and not from those centres of gravity, there must always be errors in the results proportionate to the distances of the surfaces from those centres.

In the case of light, though the magnitude of the error is often nearly the same, the cause of it is always very different. It is doubtful if there be in nature any such thing as a luminous point; and in all cases of light originating in any body, it originates at the surface and not at the centre of gravity, or any other point within the substance of the body. It is from the surface that the changes in the intensity of light, for different distances, must be begun; and as the rays proceed in all directions from every point of that luminous surface, there must be more illuminating power in a large luminary than in a small one, even though an equal surface of the smaller one has an equal, or even a greater, illuminating power.

Upon this principle we can explain the very limited distance at which the light of a lamp or candle is seen, even compared with that of a larger fire, such as the burning of a heath or furze on a moor, of which the light, when seen from a very short distance, is much less bright, space for space.

The motion of light is exceedingly rapid; for it passes over the mean distance of the sun from the earth, which in round numbers is 95 millions of miles, in eight minutes and a half, that is, at the rate of more than 180 thousand miles in one second of time. We cannot, even if accustomed to very nice observation, divide time more minutely than to the tenth part of a second; but even if we could divide it to the hundredth part, the same portion of light would be gone to the distance of about two thousand miles before we could take any note of it. Thus, before we can look at a single letter of a book, so as to know

the form of it, the light by which it was revealed to us, if the eastern light of the morning, will be as far away as the atmosphere over America. Sometimes we see the moon in the west, after the sun has risen, or when the sun is rising, in the east. Now, if, when this is the case, we are up in time, and see the first ray of the sun break over the horizon, that very ray will have passed on 240,000 miles to the moon, and the same distance back again, by the time that we have turned round, and got sight of the moon, let us do it as quickly as we may.

The rate of the wind, when it blows the most dreadful hurricane, which uproots the trees of the forest, levels houses, and absolutely blows the land into the sea, is not more than 100 miles an hour, and its force is then equal to about 49 pounds on the square foot of a surface directly opposed to it. The space over which light passes in an hour is more than 666 millions of miles, or nearly 7 million times faster than the most violent hurricane. When fluids of equal densities, that is, containing equal quantities of matter in equal bulks, move with different velocities or rates of motion, the forces with which they strike the same object are as the squares of their velocities. So that if light were a fluid, and had the density of air, the effect of it would be dreadful.

The square of the velocity of light is to that of the hurricane, nearly as 49,000,000,000,000 (forty-nine billions, or millions of millions) to 1; and taking that at 49 pounds on the square foot, the light of the morning would fall on a man's face with a force of more than 600,000,000,000 tons—a force which is altogether beyond the range of human understanding, but which would certainly be sufficient to pound the globe into dust, or blow it into vapour. But instead of causing destruction, or even pain, the sensation of the light is pleasurable, and all its effects are too fine for being examined by the very nicest mechanical means that we can apply. If there were in every mile, nay, we may say, in every thousand miles of the sunbeams, a quantity of light that

could be weighed, those beams would strike like spears, and destroy the whole economy of nature.

Light is indeed a wonderful thing. Its power of action, from the tremendous velocity which has been stated, and the accuracy of which there is no reason to doubt, is beyond all human comprehension great; but so beautifully are the workings of the Almighty balanced, that while the action is inconceivably strong, the agent is as inconceivably weak and gentle. Yet, notwithstanding its extreme rareness, light is as susceptible of mechanical division as the most solid substance with which we are acquainted. It is true that we cannot divide it across so as to obtain different parts in length of the same ray; because, before we can move our dividing instrument a single hair-breadth, the part of the ray most distant from the luminary will have escaped to the distance of many thousands of miles.

In the passage of light through substances, it is not their compactness which arrests its progress, it is their structure, or the way in which their parts are aggregated. Diamond is, perhaps, the most compact substance that we know; and yet, unless diamond is coloured by having some foreign matter mixed with it, it is quite transparent; and there is some reason to believe that light passes more rapidly through it than through air or even empty space. But, grind the same diamond to powder fine enough, and it is no longer transparent.

Water may be mentioned as another and a more familiar instance. Liquid water is the heaviest, and therefore we may suppose the closest form of that substance, and yet clear water is beautifully transparent. Ice is less so; but the more heavy, and therefore solid it is, the more transparent is it; yet reduce the ice to powder, or let the water fall in the form of snow, and its transparency will be gone; and if the particles of it are very fine, it will stop the progress of the light altogether, and return it back again in the most intense and beautiful white.

Every substance through which light can pass is called

a *medium*, and different *media* have different degrees of transparency, and act differently upon light.

Of the nature of vacuum, or space entirely empty, we can of course say nothing; because it can have no properties. Besides, when we consider the immense rarity of light as compared with the air of the atmosphere, our imagination cannot set bounds to the rarity of matter; and though we cannot positively say that there is matter a thousand times rarer than light, as little can we deny that there may exist matter countless millions of times rarer. With God all things are possible both in existence and in action; and we can neither assert nor deny beyond the limits of our knowledge. When, however, light passes through that which to our observation is vacuum, or empty space—that is, through any vessel which we have so exhausted of matter as that which remains in it shows no weight, nor by any other of our tests indicates the presence of matter, the light reveals nothing to us. It is therefore consistent with our ordinary forms of expression to say, that light, which reveals all visible things to us, is in itself invisible, and gives no sign whatever of its existence, except by means of something else which we can examine and know to be material.

There is one subject which it is impossible to avoid noticing here, and that is, the extraordinary delicacy of that part of the eye which is the immediate organ of vision. The intelligence of external things comes to the eye at the rate of 18,000 miles in a second, which is more rapid than if it six times encircled the globe between the two beats of a healthy pulse; and yet a good eye can seize and keep perfect intelligence of every outline of form and every tint of colour. Thus, while we cannot but admire the wonderful nature of that light which is the glory of the material creation, we have far more reason to admire and to be grateful for that adaptation of our organs of sight by which we are enabled to enjoy all its beauty and all its usefulness.

Section XIV. Particular Appearances of Light.

In the former Sections we have spoken of light in itself, and regarded it (if a substance at all) as a simple substance, proceeding at a uniform rate, and in straight lines, because that simple view is necessary as preparatory to a proper understanding of the appearances of light. But light is not a simple substance; and the light of the sun, which is the most familiar, the most useful, and the most perfect light with which we are acquainted, is a compound of very many substances, or at least modes of action, some of which, and those, too, probably among the most powerful, and the most important in the operations of nature, do not appear as light at all.

The sun and stars are not, however, the only sources of light; for all bodies give out light by radiation, when their temperature is raised so high as to produce what is termed incandescence. Radiant light proceeds in all directions, diminishing in intensity as the square of the distance increases.

From whatever source light proceeds, it is partially radiated, reflected, or thrown back from the surfaces of all objects on which it falls, and in that way it reveals them. Radiant light shows us the forms and the colours of objects.

Smooth surfaces (and those of transparent bodies are generally such) reflect as well as radiate the light which falls on them. In certain states also they transmit it; and it is because they transmit light, that we call them transparent substances. All bodies also absorb, or render invisible, a part of the light.

The comparative results of these modes of action cannot be stated in general terms, because they vary with the nature of the body, and the position in which the light falls on it. Thus, of light falling at right angles, water reflects at the first surface, 15 parts in 1000, and glass 25; but at an angle of $2\frac{1}{2}$ degrees, water reflects 614 parts, and glass only 584.

To investigate all the variations in the action of light is a long as well as a most interesting study, and even the portion of it which comes within any one's observation is in many instances very complicated; so that the systematic writers on *Optics*, or the science of light, find convenience in dividing it into three principal branches, besides some subordinate ones. These branches are, *Dioptrics*, or the phenomena of light in passing into, through, or out of substances, or media, which are more or less transparent; *Catoptrics*, or the phenomena of light, when it is reflected or turned away from the surfaces of bodies, whether those bodies be transparent or not; and *Chromatics*, or the appearances of coloured light.

Section XV. General Law of Dioptrics.

When light proceeds dioptrically, that is, through a transparent body of uniform density, it proceeds in straight lines; and if the body were perfectly transparent, the light would leave it with precisely the same intensity as it enters; but as there is no substance with which we are acquainted perfectly transparent, there is none which does not to some extent diminish the intensity of light.

When light passes from a rarer medium into a denser, at an oblique angle, it is turned nearer to the perpendicular to the surface, and more of it is reflected at that surface. On the other hand, when it passes out of a denser into a rarer, it is turned farther from the perpendicular.

These changes in the direction of light, in passing from one medium to another obliquely to the surface at which they meet, are called *refractions*. If the path of the light be at right angles to the surface bounding the substance, there is no refraction.

When the light is transmitted in one undivided or undecomposed portion, the refraction is said to be *simple*.

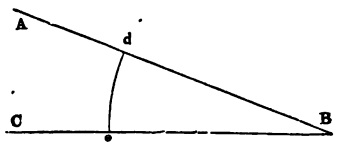
Light is said to be *incident* upon those surfaces on which it falls, and *emergent* from those which it leaves. The angle which the light makes with the perpendicular

when it is incident, is called the angle of *incidence;* and the angle which it makes *within* the substance, is called the angle of *refraction.*

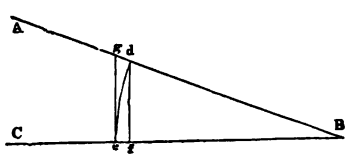
Different substances have different refractive powers; and the change produced by refraction in the same substance varies with different angles of incidence; but in the same substance, the *sines* of the angles of incidence and refraction have the same proportion to each other, whatever the angle of incidence may be.

Here it may be proper to explain, for the sake of those who do not know, what is meant by the *sine* of an angle; and as we shall afterwards have occasion to mention some other lines related to or connected with angles, we shall add short definitions of them.

Any two straight lines which meet at a point form an *angle,* the magnitude of which depends wholly on the *inclination* of the lines, and is not affected by their length. The lines A B and C B form an angle at the point B in the following figure.



Now, if one foot of a pair of compasses is set on the point B, and the compasses opened to any distance less than B A or B C, it is evident that an arc, or portion of a circle, could be drawn to meet both lines, such as the arc d e. The arc d e is said to be the measure of the angle at B, or conversely, the angle is the measure of the arc: and the one of these is the measure of the other, whatever may be the length of the lines B d, B e, which are evidently both of the same length. Well, repeating the figure, suppose a line to be drawn from d toward the line C B, at right angles, or the shortest distance, and that



line met C B, in the point f, the line d f would be the *sine* of the angle at B.

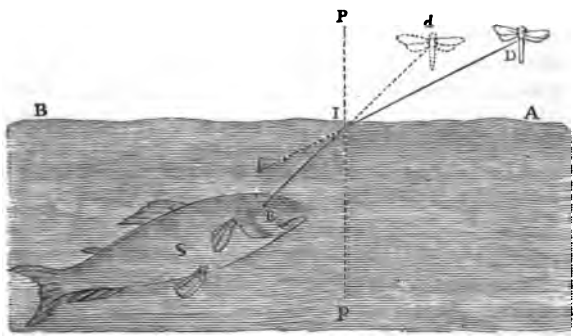
Suppose, again, a line drawn from the point e in the line C B, towards the line A B, in such a manner as that it would touch the arc at e, but not cut it or come to the side of it on which B is situated, either above or below the line B C, the line e g, so touching, but not cutting the arc, would be the *tangent* (that is, the 'toucher') of the angle at B. So also, the line B g (part of it without the arc, and part within) would be the *secant* (the 'cutter') of the angle at B.

B d, or B e, the distance taken in the compasses, is the *radius* or ray of the arc.

B f is the *sine* of another angle which, together with the angle at B, would make exactly a right angle. But when two angles taken together make a right angle, each of them is called the complement of the other; and in compound words *complement* is shortened to *co*, so that B f is the co-sine of the angle at B.

Section XVI. Illustrations of Refraction.

The following is about the simplest case in illustration of refraction.

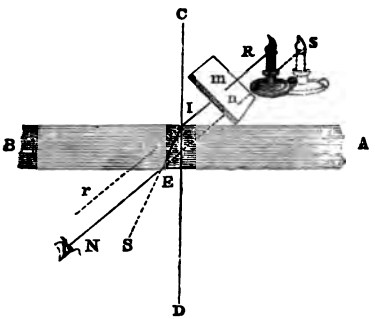


Let A B be the surface of water; D a dragon-fly hovering over it; D I the incident ray; D I P the angle of incidence;

and f I E the change of direction toward the perpendicular, so that the refracted ray I E might reach the eye E, of a fish S, ready to spring and make a mouthful of the fly. The fish would not see the real fly at D, but an imaginary fly at d, and if he should spring at that he would miss his prey. The fish must therefore see by *instinct*, and not by *reason*, as we do.

The law may be further illustrated thus:—

Let the shaded space A B represent a thick flat piece of transparent glass, suspended in the air, and C D the perpendicular to it; also, let R I be a ray of light from a luminous object at R, and let it be incident upon the upper surface of the glass, or pass out of the rarer medium into the denser, at the point I.

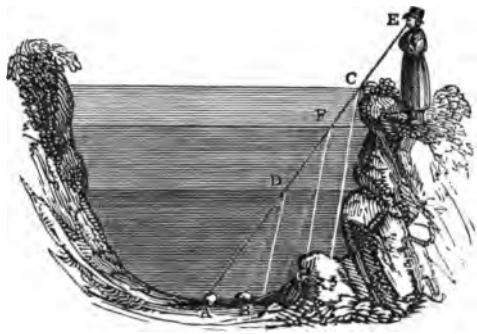


The angle R I C is the angle of incidence. At I the ray is bent toward the perpendicular in the direction I E; and E I D is the angle of refraction,—the angle E I r being the change of direction. If the glass continued lower than E, the ray would proceed in the direction E S; but as the ray again meets the air at E, it is there refracted as far from the perpendicular as it was refracted toward it at I; and it proceeds on in the direction E N, parallel to its first direction, but not in the same straight line with it.

If the ray of light were let in through a small hole in an opaque plate, an eye at N would see the luminous object through the glass and that hole, as if in the position S; but if the glass were removed, the luminous object could not be seen through m by the eye at N, but at r;

and if the eye remained at N after the plate were taken away, the object would have to be removed to S, and would be seen through another hole, n.

If the passage of the ray were from a denser medium into a rarer, the circumstances would be reversed. Suppose a man to stand on the bank of a rivulet and look over



the edge, as at E, towards the bottom, under the different states of the channel, dry, filled with clear water to D, and again to F, and lastly to C, the parts of the bottom which he would see would vary. When empty, he would see no part of the bottom and bank from A to C; if the water rose to D, he would see to B; if to F, he would see to G; and if to C, he would see the whole. Every time the water was raised, the bottom would appear to rise along with it, so that he would have an erroneous notion of the depth; and the more obliquely he looked on the water, the deception would be the greater. For the same reason, the part of an upright post which is in the water always appears shorter than it really is; and when a post is oblique, or leans, the part which is in the water always appears to lean more than the part which is in the air, so that the post seems bent at the surface. In consequence of this deception, it is very difficult to hit a small object in the water, if it be looked at obliquely; and the same

deception has sometimes induced people to attempt fording rivers that were in reality beyond their depth.

In the passage of light from rarer media into denser, the angle of refraction is always less than that of incidence; but when the passage is in the opposite way, and the media the same, it is the reverse.

If the transparencies of substances and also their surfaces were perfect, there would always be a tendency in the light to 'turn into' the denser substance; but as there is no perfect transparency or surface, the light is partially reflected from the anterior surface; and it is also partially dispersed by even very small inequalities of the surface.

When a ray of light passes from a denser into a rarer medium, it is just as much an incident ray as when it passes from a rarer to a denser; but when the refractive power of any particular substance (which is the difference of the sines of those angles) is spoken of, incidence upon the denser substance is always meant, and thus the angle of incidence is stated as the greater.

The proportions of these sines may be stated in numbers, and the ray considered as incident out of air. In this way the following are nearly the proportions for three substances:

Substance.	Sine of Incidence.	Sine of Refraction.
Water	13	10
Glass	15	10
Diamond . . .	25	10

The sine of incidence, answering to sine of refraction 1, or 10, or 100, or 1000, &c., is called the *index of refraction.*

The above are only approximations; but they will serve to explain the principle.

The angle of refraction at the anterior surface becomes the angle of incidence at the posterior, and the refraction there is *from* the perpendicular. Hence it is quite clear that if the angle of *escape* from that surface, the sine of which bears the same proportion to the sine of the angle of incidence there that the sine of the angle of incidence

bears to that of refraction at the anterior surface, were a right angle or greater, no part of the light could pass through.

The natural sine of a right angle may be taken as any number, if the sines of other angles are expressed in terms of the same. Take 100 as an approximation; and then the proportions of 10 to 13, to 15, and to 25, (each in terms of 100,) will give 77, 66, and 40, as the natural sines of the largest angles at which light can fall on the posterior surfaces of water, glass, and diamond, so as to pass through; 77 being nearly the natural sine of 50° 22′; 66 nearly the natural sine of 41° 19′; and 40 nearly the natural sine of 23° 5′. Therefore,

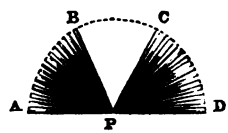
All light that falls on the posterior surface at a less angle than 50° 22′ in water,
41° 19′ in glass, and
23° 35′ in diamond, will pass through each of the substances respectively.

90°, or a right angle, is the perpendicular itself, and therefore the largest possible angle of incidence; so that, if those angles are subtracted severally from 90°, we shall have the proportion of light that each will reflect from its posterior surface, and also the range through which it will continue so to reflect, namely:—

Water . .	39° 78′,
Glass . .	48° 81′,
Diamond . .	66° 65′.

It is in consequence of these differences that glass is more brilliant than water, and diamond more brilliant than glass. This may be illustrated as follows:

If a hemisphere of light fall in all directions upon the inner surface of a point of diamond P, all that falls within the lines PB, PC, will pass through and be lost, and all that falls between those lines and the direction AD, will come out and show the lustre of the gem.

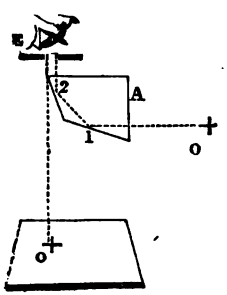


But if instead of being a plane surface, on which the central part of the light fell perpendicularly, the inner surface of the diamond were cut into facettes, in the form of a pyramid, something resembling this figure, with a flat table on the top, and if the angle of the pyramid were such that all the light that fell on the facettes fell at a greater angle to the perpendicular, the whole of the light would be reflected out of the stone, and it would be what is called a brilliant.

Diamond is the only substance capable of producing the perfection of this internal reflection from refractive power, but being a very costly substance, it is chiefly used as an ornament, and as glass is cheap and easily worked, it is in most cases preferred for useful purposes.

Glass does not reflect light from its inner surface, unless that light fall at an angle with the perpendicular exceeding 41° 19′, and thus its lustre is feeble compared to that of a diamond; but still glass prisms convey not only white light but coloured light, with the tints not much altered, in directions where it could not otherwise be had. It is necessary that the prisms should be defended from cross lights, and that their forms and positions should be true; but still that may be done with so much perfection, that a man in a dark cellar may see any object which is visible from the outside of the house.

The *Camera lucida* is a very neat application of the same principle, and it has the advantage of being more portable than most instruments intended for similar purposes. A is a cross section of a very small four-sided prism of glass. The upper angle at A is a right angle; and the other angles are so proportioned that the light which passes in at the face A, falls



on the faces 1 and 2, at angles less than 41° to those faces; so that after being reflected at 1 and 2, the light comes through a small hole at E to the eye, at right angles to its original direction.

When objects are seen by reflection from plane surfaces, whether they be the inner surfaces of transparent media, or the outer surfaces of opaque bodies, they are always seen in the last direction of the rays of light, because there is nothing to carry forward to the perception of the observer any of the angles which that light may have made in its progress. Hence the object at o, at right angles before the face A of the Camera lucida, is seen in the direction o, at right angles below. A sheet of paper is placed there, and the little plate, or eye-piece, is so adjusted that the eye can, at the same time, see the representation through the prism, and the paper, the hand, and a pencil by the side of it, so that, if the paper is shaded from cross lights, the drawing can be traced.

It is in the arts chiefly, indeed exclusively, (if we except the inner faces of perfect natural crystals,) that we can make use of this species of reflection; for as the surfaces of masses in nature are all affected either by gravitation or by those causes which counteract or disturb gravitation, the many natural appearances that depend on refraction are from irregular surfaces.

Section XVII. Refraction of Light by Curved Surfaces.

Refractions at plane surfaces alter the positions of objects, and their forms and magnitudes to some extent, especially when the observer is in one medium, and the object in another. But their effects in the last of these ways are very limited as compared with those which are produced by curved surfaces. Considering light as *one* substance, all the rays are equally bent at the surfaces, and they are all parallel in passing through any medium of uniform density. This is not indeed true, when we

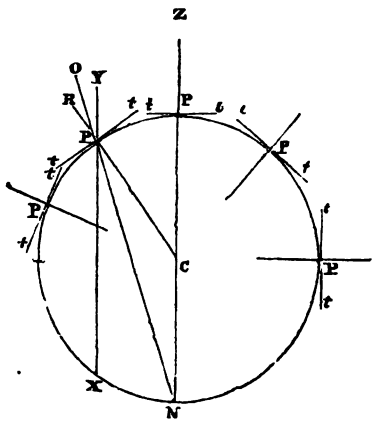
consider light as a compound; but that view of it can be taken with more advantage afterwards, so, in the mean time, we shall continue to consider it as simple, that is, as being equally affected in all its parts.

The angle of refraction does not depend upon the form of the surface, but is constant to its law in the same substance, varying in its magnitude only with the angle of incidence. Hence, when the boundary is a curve, it is impossible for the rays of light to pass from one medium to another of different density, without having their parallelism disturbed in proportion to the degree of curvature, whether that curvature be in one direction, as in part of a cylinder; in every direction the same, as in part of a globe; or in many different directions, as in an egg-shape. Nor is it of any consideration whether the surface be convex, like the outside of any of those substances, or concave, like their hollows, or like casts or moulds taken from their outsides; for though the changes are opposite, because the curves are so, the same degree and form of curvature produces the same extent of change.

In a curve, whatever may be its form, and whether convex or concave, the perpendicular at any point, is always the perpendicular to the tangent at that point; that is, to the line which touches it at that point, but does not cut or cross it either way. No two of these perpendiculars can be parallel, nor can they be in any way in the same direction, unless they are parts of the same straight line which, continued, would pass through the centre of the curve, and be the axis, or diameter of it.

If the curve is convex, these perpendiculars will converge, or come nearer to each other as they approach towards it; and if it is concave, they will diverge or get farther asunder. The following portion of a circle will illustrate the principle with reference to both sides of the curve.

P, P, P, P, P, are five points in the circumference of a circle, of which C is the centre. The lines *t t*, are tangents at those points; and the lines at right angles to



the tangents, drawn through the points P, and tending to the centre C, are the perpendiculars; and it is seen by mere inspection of the figure, that the lines converge from without the circle to the convex circumference, and diverge from the centre to the concave.

If a ray of light fell upon the curve externally from Z toward N, or internally from N toward Z, it would pass on without any refraction, because Z N is at right angles to the curve.

But if another ray parallel to the former fell from Y to P to your left, it would not pass on in the direction X. If the curve were denser than the medium without, it would be bent toward the perpendicular R C, in proportion to the refractive power, (the discovery of which for the particular substance is a matter of observation,) and to the angle R P Y, which can be calculated. Supposing both to be known, it would take some direction between P X and P C, and would meet Z N in some point, say in N. It would be easy to show, that if the curve were adjusted to this refractive power of the medium, and that medium of an uniform density, the rays of a parallel beam of light would, from all points of the curve, be directed to the same point, which point would be the *focus* of the curve.

The distance of the focus would depend on the substance, as well as on the curve. It would be nearer for diamond than for glass; nearer for glass than for water; and nearer for water than for air—if it were possible to

obtain a detached mass of air surrounded by a vacuum, which it is not.

If the motion of the parallel ray were in the opposite direction, from X to P, the refraction would be the same in extent, but the other way; and the ray would spread outwards in the direction P O, and pass onward through the denser medium, as if it had come from the point N in the rarer, which we must in this case consider as being within the circle.

Thus, when parallel rays of light fall upon the convex surface of a denser medium, they converge toward a centre on the opposite side from the light; but when they fall on the concave, they disperse as from a centre situated on the same side with the light. So, the one form condenses the light, and brings it to a focus, and the other scatters it.

SECTION XVIII. OF LENSES.

THESE principles, simple as they are, have been of vast service to mankind, for upon them all the dioptrical instruments which are in any way used to improve and assist the sight are constructed. The essential parts of these instruments, whatever may be the purposes for which they are intended, are all called lenses. They are usually made of glass, occasionally of rock-crystal, and sometimes, for very nice purposes, of diamond. Of the glass ones, those which are made of the most weighty glass are the best; but they are the weakest, and the most apt to become tarnished. Where diamond can be employed it is far better than any other substance, as it is more transparent, has more light and power, and nothing will scratch it; but it can be employed only for very small instruments.

Lenses are of various forms. Those most commonly used in the construction of optical instruments are as follow:—

A. A *plane lens*, flat on both sides and of equal thickness in all its parts.

B. A *plano-convex*, which is flat on one side and convex on the other.

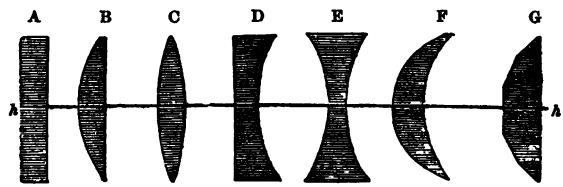
C. A *double-convex*, that is, convex on both sides.

D. A *plano-concave*, flat on one side and concave on the other.

E. A *double-concave*, or concave on both sides.

F. A *meniscus*, which is concave on one side and convex on the other, and

G. A *flat plano-convex*, or multiplying-glass, having its convex side ground into several flat surfaces.



A right line at *h h*, passing through the centre of a lens, is called its *axis*.

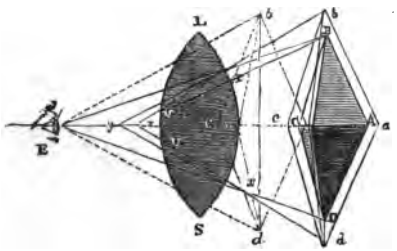
The optical instruments themselves are, telescopes for viewing distant objects, microscopes for viewing small ones, and spectacles and eye-glasses for assisting the eyes either by concentrating the light or by dispersing it. All lenses which are upon the whole convex, or thicker in the middle than at the sides, concentrate the light, and all which are of the contrary form disperse it, whatever may be the particular forms of their sides. Those which concentrate the light, magnify; and those which disperse it diminish, in the proportion of those qualities.

We found our judgment of the magnitude of objects upon the angles which their lineal dimensions subtend at the eye, and the clearness with which their parts are seen, jointly. But there is a good deal of habit in the way that these two elements of judging influence each other.

If the object be one with the size of which we are very familiar, as a man, a house, or a tree, the feeling is that it is brought nearer; but if it be an object, the parts of

which we can distinguish only imperfectly by the naked eye, as a little insect, or the markings upon a small flower, the impression is that its bulk is enlarged. There are also intermediate cases, in which we feel as if both changes had taken place. The instruments which seem to bring distant objects near, are called *telescopes*, or 'far-sighters;' and those that seem to make small objects large are called *microscopes*, or 'small-sighters;' and the 'sights' afforded by telescopes are long in proportion as the telescopes are more powerful, while the more powerful the microscope is, the sight is the shorter.

The following figure will show the general principle on which a convex lens magnifies.



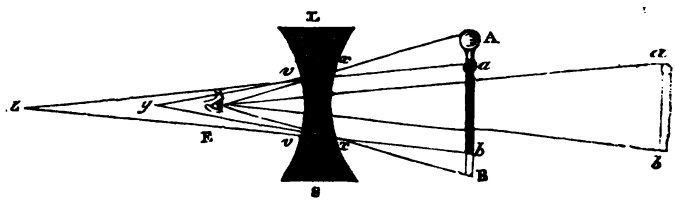
Let A B C D be an object, seen by an eye at E, through the lens L S. The angle B E D, is the *natural* angle under which the object would be seen if the lens were not there. But when the rays B E and D E arrive at the points *x*, *x*, they are refracted nearer to the perpendicular, and would meet in some point *y*, nearer the object than the eye is; and if the eye were not moved to that point, the object would not be distinctly seen.

But, if the side of the lens toward the eye is also convex, as in the figure, the rays *x y*, *x y*, will in passing out of the denser convex medium into the rarer concave one at the points *v v*, be again refracted towards the axis E C, and will meet at some point *z*, between the lens and *y*; so that, in order that the object may be seen, the eye must be moved to the point *z*.

The ray which is made up of the three parts B *x*, *x v*, and *v z*, will appear to come in the last direction, that is, in the direction *v z*, because the direction in which it

falls on the eye is the only means that we can have of knowing the direction of light. But the direction of every ray from the object will be altered in the same proportion, and the outline through the lens will be the magnified outline *a b c d;* and if it be an object of which a particular magnitude has not been fixed by experience, it will seem magnified to that extent. But if it were one with the dimensions of which the observer were so familiar, that he assigned it the same magnitude whatever the distance were, then the impression would be that it had been brought nearer to the eye, as in the dotted lines *a b c d.*

The following figure will in like manner illustrate the effect of concave lenses :—



Let A B be an object, seen by an eye at E through the concave lense L S. A E B, would be the *natural* visual angle, if the lens were not there. But the rays A *x* B *x*, falling upon the concave surface *x x*, are refracted from the perpendicular, in the directions *x v*, *x v*, and would meet at the same point *y*, behind the eye. But as they again fall upon the convex surface of the rarer medium (or, which is the same thing, pass out of the concave surface of the denser one) at *v* and *v*, they are again refracted from the perpendicular, and will meet at the same point *z*, behind *y*.

They will have the last directions *v z*, *v z*, so that in

order to see them, the eye must be removed back to *z*, and the object will be diminished to the size *a b*, or if size has been associated with it, it appears as if removed to the position of the distant *a b*.

Section XIX. Application of Lenses.

As it is not possible by any process of art to obtain a perfectly smooth surface, rare to obtain a piece of glass of uniform density, and still rarer to get it worked perfectly true, there is no lens which transmits all the light which falls upon it; and most lenses disperse much of it at both surfaces. Thus, the fewer lenses that are used in a compound instrument, the vision is the clearer, and the objects seen through it the better defined.

If the lenses are powerful enough for sufficiently magnifying very distant objects, they are never true at the sides, if portions of spheres; and as the light falls obliquely on them there, it is decomposed, and faint rainbow tints spoil the view. The first of these faults is in part corrected by altering the curvature a very little toward the edges of the lens, and the second by compound lenses, made of matters having different refractive powers, so that the one removes the colour produced by the other. These are called *achromatic*, or 'colourless' glasses; but fine ones are difficult to make, and those which are inferior destroy the quantity of light, as much as they improve the quality.

Concave spectacles, whether concave on both sides, or on one only, or concave on the one and convex, or less concave, on the other, are used by near-sighted people; and convex by those who see best at a distance. It is commonly said that in near-sighted persons, the natural lenses of the eyes (which bear some resemblance to achromatic glasses) are too convex; and it may in so far be true, for many near-sighted persons see minute objects remarkably well. It is said, also, that long-sight in age is owing to the flattening of the lenses of the eyes; and that may also

be true in some cases, though there are others in which the sight gets dim for all distances. So little is known about the process of sight, except by comparison with instruments, (and the comparison is one from which no certain conclusion can be drawn,) that no decided opinion can be given on the subject.

The largest lens upon which we have any opportunities of making observations, is the atmosphere; but as, even in its pure state, it is not an achromatic lens, our observations of it are far from perfect. Still the atmosphere is a very curious lens; and the changes that it produces on the appearances of light, and of visible objects, both in consequence of the states of the different parts of itself, of the various matters it contains, and of the numerous changes which these undergo; together with its being the immediate element in which we live, make all our observations, and perform all our operations, render it a most interesting subject of study.

This is not the proper place for saying very much respecting it; but as it is from the atmosphere that we get much of our light upon all occasions, and the whole of it when clouds hide the luminaries, the mere outlines of the doctrine of light are incomplete without it.

Taken in itself, and without any allusion to disturbing causes, the atmosphere is a transparent shell of matter which rapidly becomes rarer as we ascend above the mean level of the earth's surface. The diminution of density as we ascend is gradual, so that, unless from winds, clouds, or other disturbing causes, there are no fixed lines, or boundaries, of stratum and stratum in it, as there are in the cases of those media which we have been considering. We cannot even define its upper limit, or the limit at which it begins to be so dense as to refract light in visible quantity; for they both vary with the state of the weather. It follows the general law, however, and when equally clear, the densest portions of it reflect the most light, and refract it at the greatest angle. They do so toward the perpendicular; which, when we look toward the sky, is the axis of

the eye, or the line joining the centre of the pupil of the eye and that of the object we look at. In consequence of this, when we see the sun or the moon through the dense air near the horizon, and bear in mind that we are not in the centre of the atmospheric shell, but distant from it by the radius of the earth, or nearly 4000 miles, and probably less than 100 from the point at which it first begins to refract light, we can easily understand why the luminary should *appear* much larger there than when it is near the zenith.

The refractory power of air, even at the surface density, is very small, and so the refracted light which comes to us in dawn, and lingers with us in twilight, must bend down to us in exceeding gentle curves—curves which advance hundreds of miles before they are sensibly deflected from the straight line. But still that makes the effect greater in the end than if the atmosphere were of uniform density, and the entire refraction took place at that height where it begins. The whole of the refracted ray has been stated as appearing to the observer to come in the direction of the part next his eye; and therefore the refractive ray of the luminaries, and the refractive magnifying of their discs, when near the horizon, are greater than if the light came from the upper part of the atmosphere in straight lines.

The very same causes explain why the dome of the heavens over us appears flattened, while the diminished luminaries seem clearer than when they are lower down. The haze and fog which are always in the atmosphere near the horizon, help to increase the effect. It is often, too, confidently said, that we judge of the magnitude of objects solely from the visual angles under which they are seen. But there are many elements in our judgment of visible magnitude; and any one who has been in the habit of viewing objects in fogs—whether the dense and palpable fogs, or the half-seen ones which often load the horizon, must in many instances have found the fog to magnify every object seen through it, very much in proportion to

the obscurity under which it was observed, and at the same time apparently remove it to a much greater distance.

Allusions have often been made to the fact, that voices and other sounds are heard at a greater distance through fogs than when the air is clear; but there are two circumstances which afford not an unsatisfactory explanation, without any reference to an actual increase of the loudness of the sound:—the dimness of the objects of sight produces partly the same effect as the same cause does at night, and the obscurity which at once magnifies and removes to a distance in the case of objects seen through the fog.

The atmosphere partakes of the imperfection of the laws in colouring toward the extremities, though in the case of the atmosphere it is a beauty and not an imperfection. There is no doubt that the gay colours of the morning and the evening are owing to the greater refractive power of the denser strata of atmosphere through which the slanting beams of the sun pass at those times. When the atmosphere has much evaporative power, and the weather is settled to be fine, there is much humidity remaining aloft in the evening sky, so that the rich succession of colours at such times is easily accounted for.

But there are many of the atmospheric displays of light, and of light unaccompanied by at least any violent action of the analogous phenomena, which cannot be accounted for by refraction alone, nor by that reflection which has been mentioned as the result of refraction; and therefore, before any allusion can be made to them, the simple laws of reflection must be noticed.

Section XX. Reflection of Light.

Besides the reflection which has been explained as taking place at the inner or posterior surfaces, even of the most transparent substances, in all cases where the last angle of refraction equals or exceeds a right angle, there is an

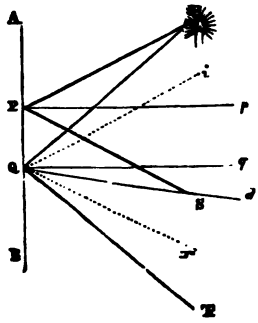
external reflection from the outer, or anterior surfaces of bodies. That more strictly speaking merits the name of reflection, because in it the light is "turned away from" the bodies, without entering into their substance at all; and the shining which is occasioned by it may be called external lustre, just as that in the former case is called internal lustre.

The direction in which bodies reflect light from their external surfaces, if they reflect it entire and undecomposed, follows one uniform law in all substances, and is not influenced and modified by differences of density, as is the case with refracted light. That general law is, that the angle of incidence and the angle of reflection are always equal to each other, but on different sides of the perpendicular. If there is no angle of incidence there is no angle of reflection, for the light which falls at right angles on any reflecting surface returns back again at right angles toward the luminous body, or other body from which it emanated; and if the rays fall at any angle with the perpendicular, on the side, they come back again at the same angle with it on the side directly opposite. In the case of a plane reflecting surface that is literally and strictly true; and hence, when such a surface is perfect, it renders back the different lights that fall upon it in all their colours, without any blending or confusion.

When one ray falls more obliquely than another upon a reflecting surface, the angle which the reflected ray makes with the incident one, increases twice as fast as the angle of incidence; for, the angle of reflection is always equal to the angle of incidence, and the angle of the reflected with the incident ray is always their sum, and from their equality equal to twice either of them.

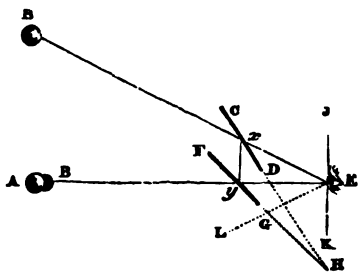
Thus, let A B be a plane reflecting surface, in which P and Q are two points, and *p* P, *q* Q, the perpendiculars to the surface at those points. Also, let I be a luminous point from which one ray, I P, falls on the point P, and another, I Q, on the point Q. The angle I P *p*, is the angle of incidence of the first, and the angle I Q *q* that of the second.

So also *p* P S, equal to I P *p*, is the angle of reflection of the first, and *q* Q T, equal to I Q *q*, that of the second.



The angle P I Q is equal to the difference of the angles of incidence I P *p*, and I Q *q*; and if the dotted line Q *i* is drawn parallel to I P, the angle I Q *i* is the difference of the two angles of incidence, I P *p* and I Q *q*. But *x* Q T, equal I Q *i*, is the difference of the angles of reflection of the two rays, I P and I Q; and the angle made by the two dotted lines *i* Q, *x* Q, is equal to the angle I P S, or the angle which the reflected ray P S makes with the same ray when incident I P. Also, if the angle T Q *d* be made double of I Q *i*, or *x* Q T, or, which is the same thing, equal to them both, it will be the difference between the angles which the reflected rays Q T and P S make with their respective incident rays, I Q and I P, and double the difference of the angles of incidence or reflection.

Hence, if the reflected rays P S and Q T were to fall upon another mirror, or reflecting surface, the difference of their angles of incidence upon, and also of reflection from, that mirror, would be double the difference of those angles at the mirror A B.



Upon this principle we are enabled to see, as if they were both at the same point, two objects, provided we know the angular distance between them. Thus, let A and B be two objects separate from each other, so that they

make the angular distance A E B, at the eye at E, it is required to show them both in the direction E A, or both at the point A. To do this, through E draw J K, at right angles to E B, and it is evident that if J K were a mirror, A E would have no angular direction, but be reflected back again toward A; while B E would be reflected in the direction of the dotted line E L, so that the angles B E A and A E L should be equal.

It is evident that two mirrors, C D and F G, could be so placed as that the ray from B to E could be reflected at x, and again at y, till its last direction were the same as that of A E; and if that were done, and the object A were seen past the side of the mirror F G, then the object B would appear in the same place as the object A, or in close contact with it.

The two mirrors must face each other, in order that they may make contrary reflections; and the angle B x y must be greater than the angle x y E, by the angle B E A, or the angular distance of the two objects, as seen by the eye at E. But the angle B x y is the angle between the incident and the reflected ray at x, and the angle x y E is the angle between the incident and the reflected ray at y; and, from what has been shown, the difference of these angles is double the difference of the angles of incidence or of reflection at x and y. Therefore the angle of incidence (that of reflection is the same) at y must be less than that by half the angle B E A. So that the perpendiculars to the two mirrors must make with each other an angle equal to half the angle B E A. But as perpendiculars all make the same angles (right angles) with surfaces to which they are perpendicular, the surfaces themselves must be inclined at the same angle as the perpendiculars; that is, if the planes of the mirrors C D and F G were produced, they would meet at H, and the angle F H C would be exactly half the angle B E A. This is the principle of a very useful instrument, which will be more fully explained hereafter.

Section XXI. Of Plane Mirrors.

Of the general cause of the reflection of light we can know very little, because the light will not stop till we question it; but it is hardly possible that it can rebound from the reflecting surface, in consequence of anything similar to the elasticity which makes a billiard-ball rebound from the cushion of a billiard-table. In the ball the motion is nothing in comparison; and there is a mass of ponderable matter, the impetus of which must be stopped and turned into the new direction. There is a measurable disturbance of the form of matter in the case of the billiard-ball, or in any other case of common elasticity; and therefore there must be a measurable destruction of motion.

The more finely the surface is polished, the better it reflects; but still, we cannot suppose that any surface of solid matter can be so polished by art, as that the inequalities of it shall not have the size of rocks, or even ridges of mountains, compared with the particles of light. It would be quite as reasonable to suppose that the rough surface of the earth would send back the showers of rain unbroken to the sky by elasticity, as that any surface could by that means reflect back the light. Yet, in so far as simple reflection is concerned, the light is reflected back entire; for all the changes that take place in it, whether in intensity or in colour, can be satisfactorily explained by refraction.

Common plane, or flat mirrors, or looking-glasses, afford the most familiar instances we have of the simple reflection of light; and as there are few houses, however humble, in which there is not a looking-glass, of some kind or other, any one may make all the experiments on reflection which can be performed with that.

A looking-glass is not, however, a mirror of simple reflection, for the glass is transparent, and if it were so pure and so well polished on both its surfaces as it is when

in a condition for making a looking-glass of the best kind, it would not reflect light at all, so as to return the image or likeness of anything, if it were not for what is called the 'silvering' at the back.

That silvering is improperly named, because there is no silver in it. It is in reality an amalgam, or compound, of tin and mercury; and though 'quicksilver' is one of the names of mercury, and expressive enough of its colour and fluidity, yet it must not be confounded with silver, as it has none of the peculiar properties of that metal.

Looking-glasses are 'silvered,' or rather tinned, in the following manner. The tin is rolled into thin sheets called tin-foil, which are laid on a plane table of smooth stone, which slopes a very little towards the end, and to which is attached a small trough or gutter. Mercury is then spread on the tin-foil, and the glass, previously polished and well cleaned, is laid on it. Heavy weights are then placed over the glass, and by this means the mercury and tin are strongly pressed between the glass and the stone. The pressure is so great that the mercury and tin are incorporated through the whole substance of the coating. The surface next the glass is an exceedingly thin pellicle of mercury, the outer surface is tin, and the centre of the coating is an amalgam of the two. The surplus mercury is pressed out by the weights, and runs into the trough at the sloping end of the stone.

Though a very common, and by no means a difficult process, the silvering of glass for mirrors combines the knowledge of many particulars:—First, when metals are melted, and their surfaces protected from the air, they have a more perfect polish than can be given to them when solid. Mercury remains in a liquid state, till the cold is so great, that if the solid mercury were touched it would stick to the fingers, and produce the same sensation of burning as hot iron; so that, at all ordinary degrees of heat, mercury has the polish and lustre of liquidity, when protected from the air by the plate of glass.

Secondly, the tendency which tin and mercury have to

combine, cements the tin to the mercury much more nicely than could be done by the application of any third substance; while, as tin is not a metal which destroys (oxydizes) very fast by exposure to the air, the external covering of it protects the mercury in the same manner as the glass protects it on the other side.

Thirdly, the surfaces of the glass and mercury do not of themselves unite, as the particles of each have to one another a greater tendency or attraction, than they have to those of the other. In proof of that, clean mercury may be kept in a glass vessel for any length of time without staining the glass; and a little mercury poured on glass forms itself into a round globule, and may be moved about as if it were a solid. But yet, it is this very attraction of the particles for each other, or this cohesion of the mercury, as it is called, which enables the workman to spread it so thin, and yet so uniformly between the glass and the tin-foil, by means of pressure, as has been mentioned. Though mercury is a dry fluid, and does not leave a pellicle of itself upon surfaces, as water does upon the surface of every substance capable of being wetted; and though in consequence of its greater cohesion it forms globules, under circumstances when a less cohesive fluid would not form them, yet mercury is perfectly fluid, and can, with little mechanical force, be divided into exceedingly small parts. In consequence of this, the pressure of the weights not only spreads the very thin film of it equally over the tin-foil, but makes it wholly exclude the air, so that every square inch of the coating is pressed to the glass by the weight of an inch column of the atmosphere, which is nearly equal to fifteen pounds. Thus, in a mirror four feet by three, which is not a very large one, the silvering is held to the plate by a pressure or force nearly equal to twelve tons.

But though the reflecting surface of the mirror has the lustre of pure mercury, it has the form of the posterior surface of the glass; and thus it depends upon the glass whether the mirror shall or shall not give true represen-

tations. If the posterior surface is rough, it scatters the light, and gives faint images, and if it is curved, it distorts their shapes. That mirror is always a bad one, which appears clear and sparkling in whatever direction we look upon it, because that shows that it disperses the light, and so cannot produce a powerful reflection of any thing.

A glass mirror produces a double reflection, one from each side of the glass, though the one from the side next the air is faint compared with that from the surface of the mercury. When the light falls at right angles on the mirror, and is of course reflected back in the same manner, the difference of the two reflections is not seen; and even when the light falls obliquely, the reflection from the front surface is not seen at any great distance; but on a near view, the two are very distinct, as may be seen by putting the point of the finger to the glass, and looking sideways at it. In that case there will seem to be two finger points, the one at the outer surface of the glass, and the other at the inner surface. That is one of the ways in which the thickness of a mirror-plate may be judged of, when it is in a frame and the edges cannot be seen. Upon the same principle, a thick looking-glass is more brilliant in oblique light than a thin one, but the thin one gives the clearer direct image.

Section XXII. Reflection from Plane Mirrors.

The right of the mirror is to the left of the observer, and the left of the mirror to his right, so that, though the image may be ever so perfect, it is reversed. This renders it awkward for people to attempt, by the help of looking-glasses, to do that which they have been in the habit of doing without them, how advantageous soever the glass may be to those who are accustomed to its use. Let one, for instance, who has been in the habit of having his hair trimmed by the barber, try to trim it at the looking-glass, and he will find it a very difficult operation, for though he

can open and close the scissors, he will move them in the opposite direction to that which he wishes.

There is more science in that very simple fact than some persons would suppose. It lets us see, that we do not judge of direction or distance, either by the eye or the hand singly, but by both of them jointly. The position to the eye is reversed, whilst the feeling to the hand is not; and thus the hand, instead of obeying the eye, moves in the opposite direction,—that being the direction to which it is accustomed. The reversing to the eye, which always takes place when we see objects by one reflection from a mirror, never alters our feeling of that which we know in any other manner. Thus the left hand seen in a mirror, is a right hand, and the right hand a left; but our seeing them as such, does not make us left-handed if we are right-handed by habit.

If, however, the reflected object be one of which at the moment of observation we have no impression, by any other sense, we cannot detect the fallacy without trying it by experience. If a gallery, as is often the case, ends with imitation folding-doors glazed with mirrors, a person who does not know the fact will feel perfectly convinced that there is another gallery behind the mirror, of the same form and dimensions, and furnished in the same manner as the real gallery; and the deception will continue till he walks up to the apparent doors and attempts to push them open.

Jewellers and others who deal in showy articles, avail themselves of this property; and, by mirrors, apparently multiply the number of articles in their windows. In matters of ornament, this use of the mirror is, indeed, a very pleasant one; as by means of it any beautiful object may be doubled to the sight, and where the sight is the only use, that is equivalent to doubling the pleasure.

When light falls upon a mirror, from any thing else than the object of which the image is wished to be seen, it always renders that image less distinct. If we place a mirror in such a manner that both the sun and the face

ought to be seen, the sun will be seen but not the face. On the same principle, the reflection of any object is less bright in proportion to the brightness of the object itself, in a light room than in a dark one, and in sunshine than in candlelight. It is upon the same principle that the tubes of telescopes, and other apertures through which light is wished to be transmitted undisturbed, are made black.

Mirrors are often applied in a very pleasing manner, in ornamental buildings near cascades of falling water. If there is in the apartment a window, or any opening through which the cascade may be seen, mirrors can be so arranged on the walls and ceiling, that a person in the apartment may seem surrounded with cascades; and if other forms of mirrors besides plane ones be introduced, the cascades may be made to appear as if they were all situated at different distances, and some of them dashing from the roof into the middle of the floor, and others spouting up from the floor to the ceiling.

In speaking of images from reflection, it is necessary to bear carefully in mind, that the image shown in the mirror, and the visual perception of that image, do not mean the same thing. The image in the mirror is always measured by the angle of vision; but our sensation of that image depends upon the judgment we have previously formed of the magnitude or the distance of the object. Thus, if our minds are made up as to the size, we imagine that the object is brought nearer by the concave mirror; if to the distance, it is made more distinct; and if both are indeterminate, it is partly the one and partly the other. In the case of a convex mirror, these circumstances are reversed.

The image of an object in a mirror always appears to be as far behind the mirror as the object is before it, and as far to the one hand as the object is to the other; and therefore, though the mirror reverses the positions of all the objects, the picture of the whole is true in its proportions.

If a mirror be so placed opposite an open window, that the reflection of the garden or the street, as it happens, is seen in it, the right and left sides will have changed places; and the end which is farthest from the front of the mirror will seem farthest behind it. If a sketch were taken from the appearance in the mirror, it would be as true to the objects as if it were taken by looking directly at them; but it would not be a direct picture, but a reverse, the same as the types from which a book, or the plate from which a print, is worked off. Artists avail themselves of this property of the mirror, in taking reversed copies for engraving, so that the prints taken from the plates may be in the same positions as the original drawings.

Of course, if the reflection is seen in a second mirror, which receives that of the first, the picture will be reversed twice, which is the same as bringing it back to its original position. In this way, a person standing with his back to the window, can contrive to get an unreversed sight of the objects before it.

Interesting as the reflection from plane mirrors is, that from mirrors with curved surfaces is still more so. Curved mirrors may have the same varieties of form as lenses: they may be of uniform curvature in all directions, as when they are segments, or portions of spherical surfaces; they may be of the same varying curvature in all directions, measured from the centre; or they may be of different curvatures in different directions, or curved the one way, and straight the other, as a portion of the surface of a cylinder or a cone. There may be an endless number of degrees of curvature in each of these forms, and any of them may be either concave or convex, so that the details of this species of reflection are very extensive.

Section XXIII. Reflection generally.

We may understand most of the appearances of light reflected from curved surfaces, by considering what has

been said of the effects of the same species of surfaces on refracted light passing through them. The reflection reverses the light, and the refraction does not; and, therefore, every other effect on the light by reflection will be the reverse of that by refraction.

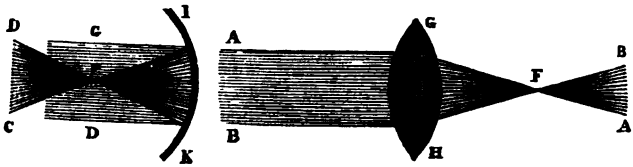
The refracting convex receives a parallel beam of the sun, and concentrates it towards a point or focus on the other side; and the concave reflecting surface turns back the light, and at the same time concentrates it to a point or focus before the mirror; and if the two have the same curvature, and act with equal perfection, the one will give a magnified image of the same size and the same perfection as that given by the other. The only difference in the use of them will, of course, be, that in the case of the refractor, the observer must be on one side and the object on the other; whereas, both observer and object must be on the same side of the reflector.

Although the convex lens and the concave mirror magnify the images of objects, they do not increase the quantity of light which originally falls on them, for there is no light produced by either; and as in lenses of great power, the rays which fall far from the centre fall obliquely, they are dispersed and do not reach the eye; so that, though within a certain range, vision by means of convex lenses is much clearer than by the naked eye, the range of distinct vision is narrowed.

As both the lens and the mirror turn the rays toward a point or focus, any instrument of either form must, if true, bring all the rays to a point at some distance behind the lens or before the mirror. The distance of that point is the focal length; and all the rays must cross each other there, and have beyond it a reverse position to that which they had before they reached it; and as there is nothing to bend them aside, they must spread wider and wider as they proceed farther beyond it.

Let A B and C D be two equal beams of parallel light, the one falling on the lens G H, and the other on the concave mirror I K. If the sum of the refractions at the two

surfaces of the lens be just equal to the reflection at the mirror, the foci E and F will be equally distant from their



respective centres, but the one will be behind the lens and the other before the mirror.

As with the mirror, the spectator stands with his back to the object, it must be seen reversed in the *lateral* position, while that seen by the lens is not; but after the rays have passed the foci E and F, where they cross each other, and spread at the same angles as they converged, they will be turned upside down, or A and C will change positions with B and D.

Both images will be most perfect in the focus, but each will admit of a little range, nearer or farther, according to the accuracy required, and admitting of a little more when the light is milder than when it is intensely bright.

The proper sight for the eye is, therefore, a little within the focus, so that the cone of light may get admission at the pupil; and the true focus may be on the *retina*, or sentient part in the back of the eye. The focal lengths of eyes vary, and therefore the same lens, or the same adjustment of a number of lenses, which suits one, does not necessarily suit another. The focal length of the glass is varied inversely as that of the eye, or requires to be longer as that is shorter, and the reverse. So much, however, depends on the *goodness* of eyes, altogether independently of focal length, that we cannot speak positively on this part of the subject. Some eyes can vary their focal lengths with the quickness of thought, while others do it slowly or not at all.

If a common magnifying-glass be held up against the

wall opposite to the window, it will be found, upon moving it backwards and forwards till the proper distance is obtained, that it throws upon the wall a correct miniature of the objects which are before the window, but in a position completely reversed or turned upside down, and not merely turned side for side, as is the case in reflection from a plane mirror; but on looking through the glass, in such a way as not to obstruct the light from the window, a similar image will be seen whose position will be perfectly correct.

It will be found, too, that the proportion between the window, and its image on the wall, will be the same as that of the distance of the glass from the window to the distance of the glass from the wall. Thus, if the window is six feet high and four feet wide, and the room thirteen feet wide, and the glass one foot from the wall, the reflection on the wall will be six inches by four. The distance from the wall is, however, not the distance of the glass itself, but the distance of its focus or point where the rays cross.

It is worth while to attend to this difference between reversing by simple reflection from a plane surface which turns side by side, and reversing by refraction which turns the image upside down. In the reflection from the plane, the rays are all bent back again at the same angle, while, in the other case, they are bent towards one point, and cross one another there, so that each comes away from that point in the direction opposite to that in which it arrives at it.

Section XXIV. Illustrations of Reflection and Refraction.

When the two kinds of reflection just mentioned are combined, the image seen from the second reflection will be righted. This is the principle upon which that well-known instrument, the camera obscura, is constructed. A convex lens receives the light into a darkened box, or

chamber; when the instrument is on a large scale, the image is received on a mirror, and that mirror reflects the image of whatever is before the lens, in a direction different from that of the original light, in proportion to the angle at which it is set. Instruments of the same kind may be made with a single concave mirror set at an angle. Indeed, though we cannot know by what action it is that the eye sees, yet in the structure of its parts the eye has a very remarkable resemblance to the camera obscura, which is formed of lenses. There is the same error in light reflected from a concave mirror, which is a portion of a sphere, as in that which is refracted by a lens of the same form, and, therefore, when a camera obscura is made to represent large views, the table on which these fall is not quite level, but is adjusted to correct that error —which is called the "spherical aberration."

A concave mirror is generally called a *speculum*, the plural of which is *specula*. It received this name because objects are magnified, and consequently better seen by means of it; and when powerful enough, it has the property of kindling inflammable substances in its focus in the same manner as a lens.

The second image formed by reflection beyond the focus of the speculum explains many appearances in nature, and some very neat optical deceptions, or deceptions of sight, in art.

Take a bright and well-polished spoon and look into the bowl of it. If you look near, you will see an erect image of your face, only reversed, as it appears in a common looking-glass; and if, as is generally the case, the spoon be egg-shaped, your features will be distorted, and the distortion will be different in different positions of the spoon.

Remove the spoon slowly from you, and the image will diminish as you approach the mean focus; near that it will vanish; and if you keep still removing the spoon you will by and by find your picture turned upside down, and it will increase, but become dimmer, as the spoon is farther removed.

If the light from objects be made to fall obliquely upon specula, it is reflected obliquely, and thus the secondary or reversed image may be seen out of the line, or even out of the sight of the speculum, as, if the object is a little below the speculum, the secondary image will be a little above it; and so for other positions.

Some very amusing deceptions may be performed on this principle. Thus, if there is a pedestal in a room, a bust turned upside down behind the pedestal, and a speculum properly placed, there is always some position in the room from which the bust seems upright on the pedestal, but it vanishes the moment you quit that position. So also, if a hole in the partition at one end of a room be made to imitate a cave, the figure or picture of a lion may be so placed on the other side, that the lion shall appear rampant at the porch of his den whenever you approach within a certain distance; but if you walk boldly up to him he vanishes, as if overawed by your presence. Many interesting experiments may be made in a similar manner, and they are improved by a combination of specula.

Telescopes are often made with specula instead of lenses, though in those which have specula, a lens or combination of lenses is used for the eye-piece, or portion next the eye. Small ones are frequently made with two specula, a large one near the eye, which is perforated in the middle, and a small one near the other end of the telescope, which is seen through the perforation. The light from the objects falling upon the large speculum is reflected from that to the small one, and from the small one to the eye. The small speculum, of course, hides part of the field of view, and the additional reflection diminishes the quantity of light. In the larger reflectors there is but one speculum, which is placed a little obliquely at one end of the telescope, and the sight is at the other end. Very powerful telescopes, having more field of view, and more light than can easily be obtained by refracting ones, have been made upon this construction; but it is exceedingly difficult to make specula of the proper

form and having the necessary fineness of polish. The form of an astronomical telescope, to which the light may be considered as all coming in perfectly parallel lines, is a portion of a paraboloid, or curve, every section of which through the axis is a parabola, that being the only surface from which parallel rays can be reflected truly to a focus.

Section XXV. Effects of Convex Surfaces.

When light is reflected from a convex surface, and the rays diverge from that surface, there is of course no crossing of the rays, and no second image; but the diminished appearances are visible at all distances from the mirror, if the distance is not sufficient for so dispersing the light as that enough of it does not fall on the eye for producing sensation. The range over which the reflection from such a mirror can be seen, increases in proportion to the diminishing power of that mirror; and thus, as ornamental parts of furniture, convex mirrors are far more brilliant than mirrors of any other form.

If the surface has curvature only in one direction, or is part of a cylinder, it produces compound reflection, whether it be viewed on the convex or the concave side.

The convex side of it diminishes in the direction of the curvature, and reflects plainly in the cross direction; and the concave side magnifies in the direction of the curvature, and reflects plainly in the cross direction. Upon these principles, a mirror of either sort will make the face appear either longer or broader than it should be; but the convex one will show longest in the cross direction, and the concave one in the direction of the curvature.

Even when the reflection is not so great as to produce images, in consequence of the light returning faintly, or only in part or coloured, convex surfaces appear much more brilliant than plane or hollow ones. A square pilaster of finely polished marble reflects the light only in one direction; and when we move out of that direction, the surface ceases to shine; but a cylindrical column of the

same marble shines from whatever position you look at it. Circular reeds and rounded mouldings are also much more brilliant in mahogany or the other finely coloured woods, than hollows or flat surfaces; and a judicious combination of the three, enables workmen of taste to communicate much beauty of effect to their works. Much of the elegance, both of houses and of furniture, depends on these combinations; so also does much of the visible beauty of everything; and the expression of the human face, which is so pleasing in some states, and so much the reverse in others, is in a great measure owing to the different positions of the different parts of its surface with reference to light. Indeed, the subject of the reflection of light is perfectly inexhaustible; and as, if we view it aright, it always reveals beauty to us, it is as delightful as it is inexhaustible.

Section XXVI. Reflection of Light to Considerable Distances.

Correct maps, showing the shape of countries, and the situations, distances, and directions of places, are very valuable; and they can be obtained only by actual surveys or measuring. These surveys are made by means of triangles, the first of which is founded on a base or line, the length of which is measured with the greatest nicety; and the lengths of the other lines, forming the triangles, are deduced from that base and the angles.

In these surveys, it is often necessary to get sights of small objects at long distances—longer than an object can be seen by light from a common surface; and when this is the case, a reflection of the light of the sun is the best that can be employed; because the rays of that light are parallel, and any distance that can be seen on the earth's surface, makes very little difference in the brilliancy of the light.

The common way of reflecting the sun is by means of Gauss's *heliotrope*, or 'turner to the sun,' which is merely

a small piece of flat mirror. The light which this throws is very great; for when it was placed on St. Paul's, the people on Epping Forest were quite dazzled by it.

We can form some notion of the effect of this mirror, by considering the gleaming light which appears from windows, a little before sun-set or after sun-rise, and also the long distance at which reflection from the surface of smooth water can be seen. The reflections from glazed tiles, bits of glass, and other small and not very smooth surfaces, are very brilliant when they come directly to the eye.

As the light from a plane surface has the same section as that which falls upon it, the heliotrope, the dimensions of which are not above three or four inches each way, reflects a very narrow beam; and when the distance is considerable, a very nice adjustment is necessary, in order to make it fall at the point where it is wanted, and also at the proper time.

This adjustment can, however, be made, and the principles are these. The angles of incidence and reflection being equal, the mirror is so placed that the sun, and the point at which the reflection of the sun is to be seen, make equal angles with a perpendicular on the centre of it. It must be set so that the reflection shall be made at a given time; and the bearings of the sun and place where the reflection is to be thrown from the mirror, and also the height of the sun at that time, and the difference of level of the two places, must be found with the greatest exactness. These being known, there are two adjustments, namely, one for *azimuth*, and the other for *altitude*.

The adjustment for azimuth consists in placing the mirror so that it exactly faces the point of the horizon precisely midway between the sun and the place of observation. Thus, if that place is due east of the mirror, and the sight is to be at twelve o'clock, the azimuth position of the mirror is south-east, and so for other cases, always half the angle of bearing at the mirror.

The adjustment for altitude consists in sloping the mirror backwards or forwards, till the perpendicular to its surface divides the vertical angle between the sun and the place of observation. If that place is on the same level with the mirror, the adjustment is obtained by leaning the mirror backward half the angle of the sun's altitude. If the place of observation is lower than the mirror, half the angle of their difference must be added to half that of the sun's altitude; but if higher, half of it must be subtracted.

But though the principles of these adjustments are simple, the adjustments themselves are so very nice, that they can hardly be made for a distance of even a few miles; because, where such observations are wanted, a telescope is always used, and the reflected light can with difficulty be brought to the field of view in that. As the sun appears to move in one direction, the reflected ray will move in the other, as if the mirror were a centre on which it turned. If the distance were a little less than ten miles, the reflected ray would move about five miles in the hour; and thus pass a three-inch object-glass in about the thirtieth part of a second, a time so short that an instrument could not be adjusted to it with certainty. Thus, though the heliotrope can be made to throw the light of the sun to great distances, if no opaque body be in the way, the chance of seeing it is so small, that it possesses scarcely any practical value, and other contrivances are therefore resorted to.

Section XXVII. Reflection from an Irregular Mirror.

One of the neatest of these contrivances was employed by the gentlemen engaged on the Ordnance Survey of Britain, forming the groundwork of a beautiful map, which, when completed, will be the best geographical picture that has ever appeared.

These gentlemen had one station on Severndroog Tower, on Shooter's Hill, in Kent, and another on the Tower at

Hanger Hill, in Middlesex. Those points are about sixteen miles and a quarter distant; and their elevation is such that the line joining them passes higher than any of the buildings of London, excepting St. Paul's, and that is out of the direction, though the line passes about the height of the centre of the dome.

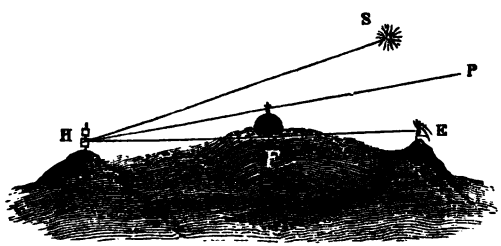
In clear states of the atmosphere, either of these places could be easily seen from the other; but the whole length of London lies between; and thus the view is interrupted by the London fog. This fog always makes its appearance when the air is cooled below a certain temperature, when the surface is moist, and the air not in that state in which it converts water rapidly into vapour. London, and the boroughs and villages around, contain nearly 400,000 fires, and when these are lighted in the morning they send up a great quantity of vapour of water and charcoal and all the materials of smoke, which the cold air above the city prevents from spreading in the atmosphere, while the warm surface prevents them from falling to the ground. This fog seldom reaches either Shooter's Hill or Hanger Hill; and, indeed, it is not often so high as the cross of St. Paul's: but it rises higher than the line from tower to tower.

Shooter's Hill was the point of observation from which it was necessary to see the object on Hanger Hill; but at the time when this part of the survey was in progress, the fog intercepted the view, so that no object could be seen through it by day, and no artificial light during the night. The only thing that had even a chance of answering the purpose was a reflection of the sun's light. Of course no reflection of the sun's light can penetrate a fog, through which the sun itself is not visible; and thus, it would be impossible to see any object through the fog if the line passed just above the chimneys. But the line between the two hills lay through the upper and less dense part,—a part through which the sun would have appeared rayless; and thus the difficulty was reduced to getting a reflection of so long continuance that there would be a chance of seeing it.

There was no hope for the heliotrope, because the angular motion of the reflected light was at the rate of about seven and a half feet in a second, and so, as we have said before, it could not have been above one thirtieth part of a second in the field of the telescope, a time far too short for any adjustment; and as the same adjustment would not answer for two days, on account of the variation of the sun's altitude, the labour of any attempt would have been thrown away.

The reflector which they substituted for the plane mirror was common tin-plate, such as is used by whitesmiths. The hammering of the tin-plate forms the surface into a number of little mirrors, not in the same plane, but nearly so. Thence it is evident that, if one of those tin-plates is adjusted for the average surface, some parts of it will begin to shine before the average time, and some will continue after; so that it will throw the reflection over a wider surface, and also continue it longer. A series of plates of this description were fixed to a post on Hanger Hill tower, the one above the other, and all adjusted to different hours. They were found to answer completely—the reflection appearing through the fog like a rayless star. The mere size of the reflecting surface is a matter of very little consequence; a single point will, in fact, answer the purpose.

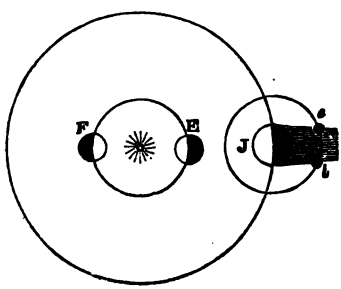
It is not possible to give upon paper a suitable diagram of the positions in this case, as the lines lie in two planes; but the following figure will afford some notion of them.



Let E be the place of observation on Shooter's Hill, H the tin-plates on Hanger Hill, F the London fog, intercepting the view, but over which the cross of St. Paul's is seen; also let S be the direction of the sun. If the incident ray S H, and the reflected ray H E, make equal angles with the perpendicular P H, at the plate H, then that plate will be seen by the eye at E, while a lower and nearer plate might not be seen, as there, the direct ray would have to pass through the fog, and the reflected ray to return through the same.

SECTION XXVIII. REFLECTION OF MOONLIGHT.

No light answers for these distant reflections but that of the sun, but it answers for distances far greater than these. The satellites of Jupiter are, upon the average, as far from the sun as Jupiter is, which is, say 500 millions of miles, and the earth may be about 100 millions farther from, or nearer to, Jupiter than that, according as the earth and Jupiter happen to be on opposite sides of the sun, or on the same side. If they are on opposite sides, the direct ray will have 500 millions of miles to pass to the satellites of Jupiter, and the reflected ray 600 millions to return to the earth, which is a journey of 1100 millions of miles. Yet in these cases the reflected light not only comes from the satellites, but the eclipses of them, as they enter the shadow of the planet, or pass out of it, are very useful in finding the longitudes of places on the earth.



The annexed figure will show this.

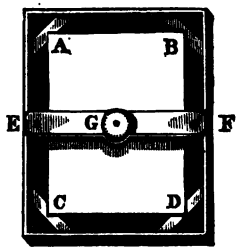
Let * represent the sun, J Jupiter, *i* a satellite entering Jupiter's shadow, and *e* one emerging from

the same; also let E represent the earth when nearest to Jupiter, and F when most distant. It is evident that when at E the earth is nearer to Jupiter by the whole diameter of its orbit than when it is at F.

It is from this that we are enabled to ascertain the rate at which light moves. The distance from E to F is about 190 millions of miles; and it is found that light takes fifteen minutes to move over this distance, which is nearly 13 millions of miles in a minute, or more than 200,000 in a second.

Reflected light from the convex surface of a planet is dispersed, and does not answer so well for a second reflection, as it cannot be seen at any great distance. The reflection of the moon is, however, a matter of some curiosity, if thrown, not from a flat surface, but from a mirror of very great focal length.

Some gentlemen a few years ago amused themselves with the reflection of the moon, from a mirror on Leith Hill, in Surrey. For that purpose they got a piece of common mirror, A, B, C, D, supported on a frame at the corners. Across the middle they put a piece of iron, E F, for carrying a fine micrometer screw, G, the point of which pressed a cushion against the centre of the mirror. The screw was gradually worked till the mirror was made a little concave, for glass is elastic, and will bend a good deal if carefully managed.



When they had brought the mirror to the proper form by the screw, they suspended it in *gimbles*, so that it had both an azimuth and an altitude motion. Then they exposed it to the light of the moon, and threw the reflection upon a village about two miles distant. The appearance, seen from the village, was very formidable; as the moon

was so much magnified, that the whole hill seemed on fire, —and fire of a very novel appearance, as it was dull and yellow, without any signs either of flame or of smoke. But, excepting amusement, it is not probable that any purpose could be served by this species of reflection. It, however, enables us to understand reflections of the moon, which are sometimes formed in clouds, and known by the name of *parcelenæ*. It is probable that these reflections come from the posterior surfaces of round clouds, which act in the same way as the concave mirror, if the observer be in the line of the reflection, as the villagers were, in that from the mirror on Leith Hill. But as the cloud is not so dense as the mirror, the reflection is much paler.

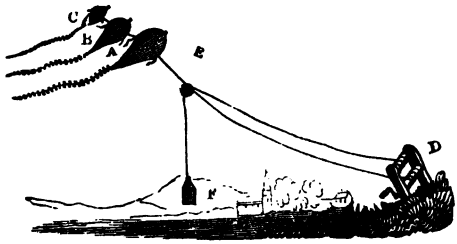
Section XXIX. Elevated Signal Lights.

In situations where a reflection cannot be seen, as when opaque objects higher than the line are situated between the points, it is sometimes of use to have a signal at a considerable height in the air. Rockets and other exploding substances, which ascend by the action of gunpowder, may be sent to many feet in height, but their path is uncertain, and their appearance is only momentary; so that they may either fail or the observer may miss them. If indeed it has to be seen through a telescope, a rocket at the distance of a few miles moves nearly as fast out of the field of view as the light from the heliotrope.

To remedy this, there is a very ingenious method by means of kites, although it can be put in execution only when there is wind to raise the kites.

Let A B C be three kites, A very large, B smaller, and C still smaller; B being attached to the back of A, and C to the back of B, the three kites rise better and remain much more steady than a single kite of equal power, as they counteract the lateral motions of each other, The kite A is peculiarly steady. It is convenient to have the line which connects the kites with the ground to wind round a small barrel in a frame at D, called a windlass, as then

it is more easily managed; and in a proper wind the kite A may be raised 1500 or 2000 feet, or even more.



A little below the kite A, a small pulley or block E, is fastened to the string. A smaller line from another barrel at D passes over this pulley, and has attached to the other end of it, the lantern F, which serves as a finder, after the kites are raised.

When, from the length of line out, the kites and the pulley at E are judged to have risen to the proper height, an assistant goes in quest of the finder F, and attaches either to the line or the lantern the light for the signal, which may be a pot of inflammable materials for producing white or coloured light, or any other contrivance for giving light that can be seen at a distance; and it may be lighted before it is sent up, or have a fuzee to light it, according to circumstances. There should be a stop on the line, so that the light may be so far below the block as not to endanger the kites, and the light must be suspended below that by a metal chain; but care must always be taken that the weight of the lantern or light-giving materials shall be sufficient to draw the rope down from the pulley at E, when it is wound off the barrel at D.

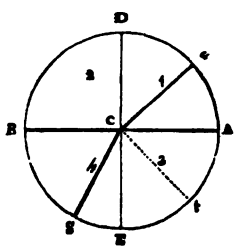
By this contrivance, signals may be repeated as often as may be necessary; and as the kites may be sent higher than the ordinary fog of the lower air, the signals may be seen at the distance of thirty or forty miles, or even more; and sometimes places double that distance asunder may be noted, by instantaneous explosions of combustible

matters. If it were possible to elevate the kites in all states of the weather, this method of making signals could be rendered more rapid than any other; but it has the uncertainty which is inseparable from everything that depends on the wind. Still, in all cases where it can be put in practice, it is very superior to most other methods of elevated signals.

Section XXX. Measuring Angles by Reflection.

From the constant equality of the angles of incidence and reflection, and the motion of light being in straight lines (except when altered by refraction, and that can be observed and allowed for), and instantaneous for all ordinary distances, reflection becomes one of the most convenient means of measuring angles.

There are many ingenious applications of this principle to particular purposes; but the most generally useful is the 'Seaman's Quadrant,' called from the inventor 'Hadley's Quadrant.' A quadrant means the fourth part of a circle, the angle of which is a right angle, or 90 degrees. Hence, if two diameters are drawn so as to divide a circle in four equal parts, each of these parts is a quadrant. Thus, if the lines A B D E are drawn, cutting each other in the centre C of a circle, so that the portions 1, 2, 3, 4, are all equal, each of these portions is a quadrant; the arches AD, DB, BE, EA, each an arch of a quadrant, and the angles at C, opposite to them, are each the angle of a quadrant.



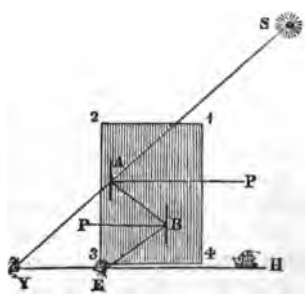
The seaman's quadrant is not itself the quarter of a circle, though, as will be shown presently, it measures angles to that extent: it is half a quadrant, or in the form

of the space A C *a*, marked off by thicker lines; and that space, being half a quadrant, is an *octant* or eighth part of a circle.

There is another instrument constructed upon the same principles, which measures larger angles than the quadrant, and which is called a *sextant*, because the arch of it is the sixth part of a circle, as the arch S B, which is contained between the lines C S and C B in the above figure. But, as the quadrant measures the whole right angle A C D, or the arch A D, while it is itself only the half of that, so the sextant measures the angle or the arch from C B to the dotted line C *t*, which is one-third of a circle, or one quadrant and one-third, or 90 degrees and the third of 90 (or 30), which together make 120 degrees; while the arch or angle of the sextant is only 60 degrees.

As the quadrant is named from the largest angle that it can measure, and the sextant from its own angle, which is only the half of what it measures, if we attended only to the common meanings of the names, we should be apt to mistake the instruments, by supposing that the quadrant which has the least range had the greatest; but though the names might perhaps have been better, if both applied in the same way, the difference is of little consequence after it has been explained.

We shall now endeavour to illustrate the principle upon which these instruments act. This explanation may be made plainer by introducing several figures to illustrate the different parts.



In these we shall consider chiefly the two mirrors, one of which is fixed, and the other moveable.

First, then, let S and H be two objects, say the sun and a ship in the horizon, which are seen by an eye

from the point Y; SYH being the angle between the objects,—or the *altitude*, or angle of elevation of the sun S above the horizon H.

Now, let A and B be the edges of two plane mirrors placed on the little board 1, 2, 3, 4, both at right angles to the board, exactly parallel to each other, and facing the directions P and P, so that PA is the perpendicular to the mirror A, and PB to the mirror B. It is evident that the board may be put in such a position as that rays from the object S shall be reflected from A to B, and from B to an eye placed at E; and that, whatever may be the angular distance of the objects, this can be done by shifting the board to which the mirrors are attached.

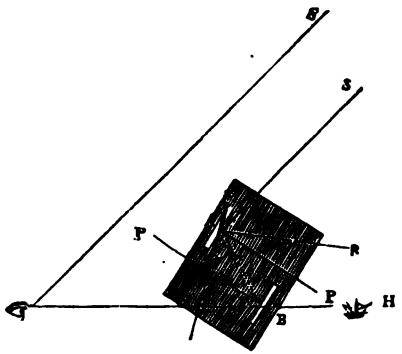
It is further evident, that as the mirrors are parallel, the perpendiculars PA and PB must also be parallel, and the angles of incidence and reflection at both, equal; that is, SAP equal PAB, PAB equal ABP, and ABP equal PBE.

By the first angle of reflection, the ray of light from S is bent from the original direction at A, and by the second angle of reflection, it is bent back again just as much at B; so that the last reflected ray BE is parallel to the first incident one SA, or, which is the same, to SY, for that would have been the direction if the mirrors had not been there. Consequently the angle BEH is equal to the angle SYH, and the measure of the one is the same as that of the other.

Let the board with the two mirrors be placed as in the following figure; that is, sloped so as that the centre of the mirror B is between the eye at Y and the object H, and let only half of this mirror be silvered, the other half left clear, as in the figure *a;* then the eye at Y would see the object H through the clear part. But in consequence of the mirror A being sloped forward, the ray from the object S would fall upon it at a much greater angle to the perpendicular PA, and be reflected at one equally increased; so that the reflected ray would not fall upon the mirror B,

a

except that mirror were continued a great way down, and even then it would be reflected still farther downward, and thus it could not be seen by an eye at any point of the line Y H. The first reflected ray would have the direction A F.

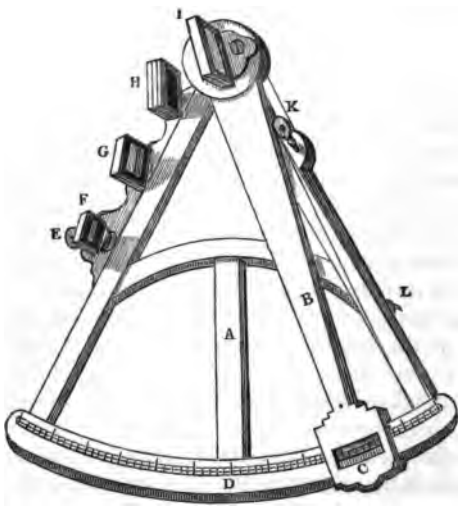


But if the mirror A is turned backward on a centre at A, in the direction of the thick line *x y*, the angle of incidence will keep diminishing; and when the mirror has been turned till the perpendicular to *x y*, namely, A B, bisects or divides into two equal angles, the angle S A B, then the reflected ray from A will fall on B, and be again reflected to the eye at Y, so that the object S will be seen in the silvered part of the mirror B, in close contact with the object H, seen through the unsilvered part.

As the mirrors were parallel to one another before the motion of the mirror A commenced, it is manifest that they are now inclined to one another precisely at the angle through which that mirror has revolved—and that angle being observed, their inclination is known. But their inclination has been shown (page 66) to equal half the angle made between the first incident and last reflected rays. And in this case, the first incident ray is parallel to the direction of the ray passing from S to the eye at Y, and the last reflected ray is *in the direction* of the ray passing from H to the same point. So that upon the whole, it appears, that the angle through which the mirror A has revolved, is equal to one half of that which rays from S and H make at the eye of the observer; and

that the former being observed, the latter is known or measured.

This is the principle of the quadrant and the sextant. The mirror, which is partly silvered, is called the horizon-glass, and it is fixed on the instrument, but in such a manner that it can be adjusted, so as to be perpendicular to the plane of the instrument, and parallel to the other mirror; this is the mirror B in the figure. The other mirror, which has similar adjustments, is fixed to an index, which turns upon the centre of the circle of which the divided arc or limb of the instrument forms a portion, and of course it moves along with the index. The



limb is accurately divided into half-degrees and parts of the circumference of its own circle; because, half a degree in the motion of the index measures a whole degree in the angular distance of any two objects. If the mirrors are parallel when the index is put to 0 at

the beginning of the scale of divisions on the limb, the instrument is properly adjusted, and fit for being used. The foregoing is the common form; but reversed by the engraver.

A the framing of the quadrant. B the index, turning on the centre of the circle, of which the divided limb D is part, and carrying the index glass I, perpendicular to the plane of the index, and in a line with 0 on the vernier scale C.

F the horizon glass half silvered, and so placed by means of its adjustment E as to be parallel to the index glass, when 0 on the vernier is at 0 on the limb D. K the sight vane, from which the horizon is seen through the unsilvered part of the glass F. G and H shades of coloured glass to protect the eye from the direct rays of the sun.

When "a sight" is taken, the index is moved till the lower limb of the sun is seen in the silvered part of the horizon glass, in the same line with the natural horizon through the unsilvered part; and the portion of the limb over which the index has been moved is the measure of the angle. In reality it is only half; but on the limb half degrees are counted whole ones.

The vernier reads the parts of degrees; thus, if that which represents a degree be divided into 4, and the vernier reads to 30, the angle is shown to half minutes, or 120th parts of a degree.

SECTION XXXI. USE OF THE QUADRANT OR SEXTANT.

FROM what has been said of the nature of these instruments, it will be readily perceived that they are adapted for measuring, in any plane or any situation, the angle subtended by any two objects. The real angle measured is that which the object subtends at the eye of the observer, but the visible angle is that on the limb of the instrument, which, from the equal diminution of the angles of incidence and reflection, is the half of the real angle.

It is of no consequence in what plane the angle lies,

whether vertical, horizontal, or oblique. Two straight lines, forming an angle, always lie in some one plane, and the reflecting instrument, whether quadrant or sextant, always gives the true measure of the angle in that plane.

The principal use of the 'quadrant' is taking the common 'sight' at sea, the object of which is to find the altitude of the sun, or the angle which the elevation of the sun makes with the horizontal line. That angle is, of course, never more than a right angle, and it is as much only when the sun is in the zenith, or directly over head, in certain latitudes, at mid-day; so that the quadrant is quite sufficient for measuring it under any circumstances. In taking the altitude, the horizon is seen through the unsilvered part of the horizon-glass, and the index is moved till the lower 'limb,' that is, the lower edge of the reflected image of the sun in the silvered part, just touches the horizon; and to make sure that the altitude is rightly taken, the instrument is moved from side to side, till the point of contact between the image and the horizon is obtained.

The horizontal plane is, in other cases, determined by a 'spirit level,' which is a cylindrical glass tube, nearly filled with spirits of wine; space being left for a small bubble of air; and when that settles at the middle, the tube is level, and any other instrument or apparatus parallel to the tube is level also. The following is the simplest form of the spirit level.

A B is the brass case in which the tube is inclosed; a portion of the case, from C to D, is open to show the tube; and the bubble of air is at E. When used alone, the level has two rests at A and B, and an adjusting screw at one of them, as at B. The screw moves the rest to which it is attached, upwards or downwards, till the line of the two rests is made parallel to that of the tube. The correctness of the level is known

by reversing it, or turning it end for end. If the bubble remain in the same position both ways, the level is correct; and if when it is placed on any surface the bubble stands at the middle, that surface is level in the direction of the instrument. So also if the bubble stand in the centre when the level is placed crosswise, a plane surface is level every way. The level shown by this instrument is a tangent to the earth's circumference, or a straight line touching the earth's surface at the centre of the level, and rising above that surface when continued either way.

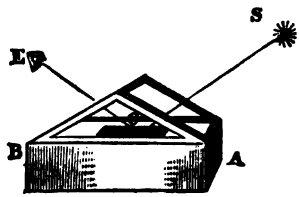
As the quadrant has no level or plumb-line, it does not refer the plane of an angle taken by it either to the horizon or to the perpendicular; and, therefore, angles taken by it, which are not known by other means to refer to these, can be referred to them only by additional observations.

At sea, the sensible horizon, being the surface of the water, is the mean surface of the globe, and, therefore, the only corrections that are required to bring it to the true horizon, are, the refraction of the atmosphere, the 'dip,' or height of the observer's eye above the horizon, and the 'parallax,' or reduction of the surface observation to the centre of the earth. Thus, the altitudes of the celestial bodies may there be very accurately found by the quadrant; but, on land, the horizon is indeterminate, and on that account an artificial one is used.

The artificial horizon is usually made of a quantity of quicksilver in a wooden trough, with a smooth and flat piece of glass laid on the top of it; and the whole covered with two panes of flat glass, placed in the form of a roof, to take off the effect of the wind. The following is a sort of representation of it.

A B is the box, with its roof, and the mercury within, and C the pane of glass floating on the mercury, which acts like a mirror, and lies horizontally, if the quantity of mercury is sufficient. S C, the incident light from a luminary S (say the sun), falls on the glass at C, and is reflected at an equal angle to the eye at E; and the angle is found

by making the image in the horizon glass of the instrument coincide with the image reflected from c, and seen through the unsilvered part of the same glass. As, in this case, the incident and reflected rays make equal angles with the artificial horizon, no correction is necessary for dip; and if the two plates of glass which form the roof, make equal angles with the plane of the glass c, the refraction of the one of them quite compensates that of the other.



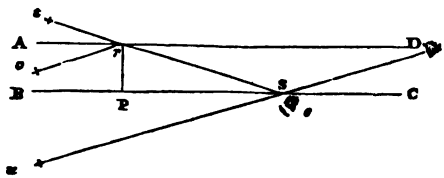
In taking other angles than those of altitude, the sextant is the more convenient instrument, as its range is more extensive; and as it is generally a more costly instrument, it is finished in a superior manner. The angular distances of celestial bodies, with a view to the determining of the longitude, are usually taken with the sextant, although when they do not exceed ninety degrees, the quadrant answers just as well. Either instrument may be used for measuring angles in ordinary surveying; and these angles may afterwards be reduced to the equivalent horizontal ones, by knowing the heights and distances of the several points of which the angles are taken. In fact, for determining positions and distances of all kinds, there are not any instruments so convenient, so accurate, or so easily used, as those which determine angles by reflection.

The principle of reflection is extended to *circular* instruments, that is, to instruments which contain an entire circumference, or 360 degrees; and these instruments, of course, measure all angles and all complements of angles. They also have contrivances by which the measures are verified with great accuracy. But such instruments are too complicated for being explained in this sketch.

Section XXXII. Repeated Reflections from Plane Surfaces. The Kaleidoscope.

Though the kaleidescope is only a toy, it is an amusing toy, and also, to a certain extent, an instructive one, as it shows the effects which may be produced by repeated angular reflections of light.

Let A D and B C be the ends of two plane mirrors, placed parallel, and with their reflecting surfaces toward each other; and let *o* be any object, a ray of light from a point of which falls on the mirror D A, at the point *r*, P being the perpendicular to A D at that point, and *o r* A the angle of incidence. As the angle of reflection is equal



to the angle of incidence, it is evident that the ray will be reflected to s, so that the angle s *r* D shall be equal to *o r* A; and to an eye (*e*) at s, the point would appear as if at *t*, on the other side of the mirror C A, and at a distance from s, equal to the sum of s *r* and *r o*.

But the ray will be again reflected at s in the direction s *n*; so that an eye at *n* would see the second image of the point, as at *u*, upon the other side of the mirror C B.

As, while the mirrors remain parallel, all the angles of incidence and refraction are necessarily equal to each other, it follows, that if the mirrors were long enough, and all the light were reflected, the number of reflections could be continued without limit; that they would be thrown alternately behind A D and B C; and that those appearing above A D (the mirror from which the first reflection is made) would be reversed, while, in those

appearing the other way, the image would be direct, or the same as the object. That is, all the odd reflections—the first, third, fifth, and so on, would give reversed images, while all the even ones—the second, fourth, sixth, and so on,—would be direct.

But if, instead of being parallel, the mirrors are placed so as to form an angle with each other, the effect is very different,—though, as the reflected rays that reach the eye, when looking between the mirrors in the direction of their lengths, or along the plane in which their edges meet, are in different planes, it is not easy to represent them by a diagram.

The general fact is, however, that if the angle formed by the two mirrors be any *even* part of a circle, as one-eighth, one-twelfth, and so on, as many images of any object placed between the mirrors at one end, will appear to an eye at the other end, as the number of times that the angle of the mirrors is contained in a circle.

These images are reversed at every reflection, so that those which lie nearest to the original object, both to the right and the left, are reversed to it. The second pair are reversed to the first pair, the third to the second, and so on, till the last reflection, which is exactly opposite to the original object, but turned the other way.

All these images are of equal magnitude, and apparently at equal distances from the centre, which corresponds to the angle in which the mirrors meet; so that they appear ranged round in a circular field or figure; and, if the end of the mirror at which the light is admitted is covered with obscured glass outside the objects viewed, so as to exclude the view of all other objects, all the images are equally bright.

Hence, whatever may be the shape of the original object, the compound image formed by the various reflections is always regular; and, as every second reflection is reversed as compared with the first, or preceding one, every two contiguous reflections produce a symmetrical figure, that is, a figure, of which the one half is the

counterpart of the other, just as the left side of the human face is the counterpart of the right.

It is from the fact of changing the most irregular figures into symmetrical ones, ranged round a circular field, that the instrument formed of two mirrors, making with each other an angle, which is an even part of a circle, is called a *Kaleidoscope*, which is a Greek name, meaning the 'sighter,' or 'exhibiter of beauty.'

If the angle of the mirrors is not an even part of a circle, there will still be symmetrical figures arising from the reversals of the alternate reflections; but the circle will not be complete, because it is only when a circle is divided into an even number of parts, that those parts are all, taken two and two, opposite to each other. If the parts of the circle are equal, but the number of them odd, as seven, nine, or eleven, the middle of each part is opposite to the point of division between two parts on the other side; and if such a circle is divided into four quadrants, by any lines whatever, the points of the odd division are never the same in all the four quadrants.

Of course, if the angle of the mirrors is not any part of a circle, the compound image will be imperfect; but still, the portions of that image will so far be symmetrical, by the one being the reverse of the other. There are many instances of this in nature; and one with which every body is familiar—the reflection of objects from water. When the surface of the water is perfectly tranquil, that is, when there is no wind or current to ripple it, and no vapour rising from its surface, the objects upon its banks are seen reversed by reflection, fainter than the objects themselves, but approaching to them in brightness when the state of the water is very favourable.

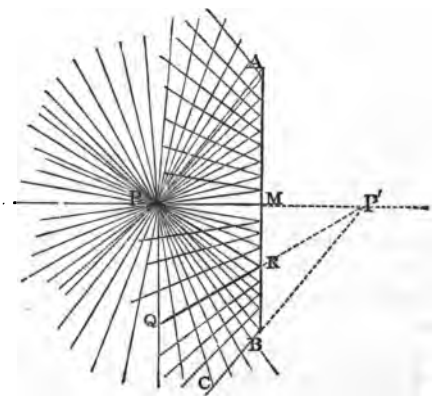
In these cases, if any object which rises just from the surface of the water be taken along with the image from the water, the two will form a symmetrical picture,—as, the semicircular arches of a bridge springing from the surface of the water will appear entire circles, half a globe

floating will appear a whole one, with half of it in the water; and when any view is seen by the reflection, it is the reverse of the natural objects.

Now, if the whole view, that which consists of the real object and the reflection,—as, for instance, that of the whole globe from the half globe, were seen in a mirror, from which other lights were excluded, the halves of it would be reversed in the direction of the perpendicular to which the planes of the water and the mirror were inclined. And if the same image were reflected from mirror to mirror, it would be reversed every time, and an observer seeing it only in one of the mirrors would see it as if it were behind that, and in the position which it had there.

Section XXXIII. Images Formed by Reflection at Plane Surfaces.

Suppose P to be a point from which rays of light diverge in every possible direction, and let a plane mirror, represented by A B, intercept a portion of these rays, it will



turn each of them back in such a direction that, after its reflection, that ray shall make the same angle with the

mirror as before. Let P R be any one of these rays thus reflected in the direction R Q. Draw P M perpendicular to the mirror, and imagine this line and Q R to be prolonged until they meet in the point P′ behind it. Then since the angle M R P′ is equal to the angle Q R B, these angles being vertical, and that P R M is also, by the nature of reflection, equal to Q R B, it follows that P R M is equal to P′ R M. Also, M R is common to the two triangles P M R and P′ M R, and they have both of them right angles at M; they are, therefore, equal in every respect, and M P is equal to M P′. Hence, therefore, it appears, that if we imagine Q R to be produced backwards, it will intercept P M produced in a point P′, as far behind the mirror as P is before it. Now P R is *any* ray diverging from P, and falling on the mirror; the same is, therefore, true of *all* such rays. That is, all the rays diverging from P, and falling on the mirror, are so reflected, that the reflected rays, if prolonged backwards, would intercept in the same point P′, situated as far behind as P is before it. Their direction after reflection is, therefore, manifestly the same, as though they diverged from P′ instead of P. And a spectator, on whose eye any of these fall, and who is not otherwise informed, will verily believe them to proceed from that point. There is, however, this difference, that rays diverge from P in every possible direction, and that point is visible any where. Whereas of those which appear to diverge from P′,—being only such as are reflected by the mirror, and have their directions within the surface traced out by lines drawn from P′, touching the different points on the edge of the mirror—none can fall on an eye situated without that boundary. Whilst, therefore, P is visible any where, provided no opaque substance intervene, there are certain positions only in which P′ may be seen.

Now the surface of every illuminated body is made up of points from which rays diverge in every direction, as from the point P, pursuing their respective paths without in the least hindering or obstructing one another. If,

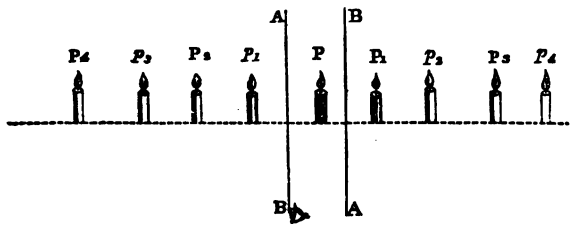
therefore, such a body be placed before a mirror, the rays incident on the mirror, from each point of its surface, will be so reflected as to have the same direction as though they diverged from a point at the same distance behind the mirror; and thus the points from which the different systems of reflected rays appear to diverge will have the same position in respect to one another, and the surface of the mirror, as the points of the object have. They will, therefore, produce exactly the same effect upon the eye of a spectator as though they proceeded from an imaginary object placed behind the mirror, precisely as the real object is before it—and that imaginary object is called *the image*. From what has been said before, it is apparent that the image can only be seen in certain positions of the eye of the observer, whereas the real object may be seen in every position, provided no opaque object intervene to screen it.

All that has been said above may be verified by means of a common looking-glass. If a person stand at any distance before it, he will see a distinct representation or image of himself, situated as far behind it. If he approach the surface of the glass in one direction, his image will approach it with equal steps in the opposite direction. If he stretch out his hand and touch one surface, the hand of his image will be similarly stretched out, and touch the opposite surface. His image will be surrounded with a mimic representation of all the objects which surround himself. If, however, he move to the right or to the left, with his eyes fixed upon the representation of one of these, he will find that, in a certain position, it will disappear, marking the boundary of the rays reflected from it by the mirror.

SECTION XXXIV. REFLECTION FROM TWO PLANE MIRRORS.

LET us suppose an illuminated object P to be placed between two plane mirrors A and B, which are parallel to

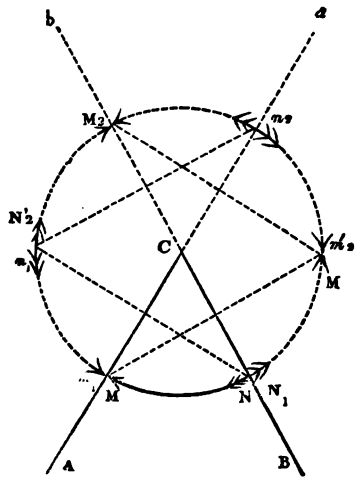
one another. The rays falling from this upon the mirror B, will be reflected, so that their directions will be the same as though they came from a similar and equal object P_1, placed at the same distance behind the mirror—and having these directions, they will fall upon the mirror A. They will, therefore, be reflected by this last mirror, so that their directions will be the same as though they came from an object P_2, as far behind A as P_1 is before it.



These again falling upon the mirror B will assume directions as though they came from P_2, whose distance from B is equal to that of P_2, and so on. In the same way the rays which first fall from P upon B, being reflected backwards and forwards, will assume directions as though they came from p_1 p_2 p_3 &c.

At each reflection, the rays falling upon the mirrors will be made to diverge farther from one another. A certain portion of them will, therefore, at each such reflection escape over the edges of the mirrors. Some of the rays being scattered by each reflection at the surface A, may be seen by an eye looking upon it from the point B. A series of images p_1 P_2 p_3 P_4 will, therefore, be visible to an eye placed there. These will, however, diminish continually in brightness, the rays diverging from them being distributed over a wider space.

Let us now suppose the mirrors, instead of being parallel, to be inclined to one another, as C A and C B, and let an object M N be situated anywhere between them.



Suppose this object to form part of the circumference of a circle whose centre is C. Now the rays falling from M N upon B C are reflected so as to form an image M_1 N_1, situated behind B C, precisely as M N is before it, and forming, therefore, a portion of the same circle. After their first reflection these rays will fall upon A C, as though they came from M_1 N_1, and will, therefore, form an image M_2 N_2, situated in one direction from A C, precisely as M_1 N_1 is in the other, and, therefore, forming a farther portion of the same circle, and so on. Thus the rays first falling from M N upon B C form a series of images M_1 N_1 M_2 N_2 &c., all lying in the circumference of a circle. Those first falling upon A C will form a similar series m_1 n_1 m_2 n_2 &c.

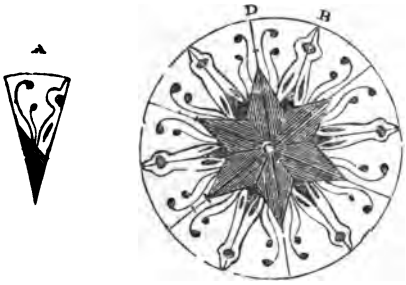
If the object M N occupy the whole arc of the circle intercepted between the mirrors, these images will be contiguous to one another; and if the arc M N be contained any given number of times in the circumference, each image will be complete, and the series will reach round the circle. If this be not the case, one or more images will be incomplete, and the series broken. The series of images will terminate with that image which first falls within the space *a* C *b*, since it is evident that rays, diverging from such an image, cannot, whatever be their direction, fall upon the faces of the reflectors. The figure represents only a section of the mirrors. In order to conceive them accurately, we must imagine them to be

continued in a direction perpendicular to the plane of the paper.

It will be recollected that the images are in each case formed, not by a solitary ray, or a few rays, in one direction, but by an infinite number of rays, emanating in every possible direction from the object, and diverging at each reflection farther from one another. A certain portion of these rays will, therefore, at every such reflection, escape over the edges of the reflectors; and each image will thus become visible to an eye looking anywhere over those edges.

The more irregular the object on the plate of glass between the ends of the mirror is, the more beautiful will be the figure.

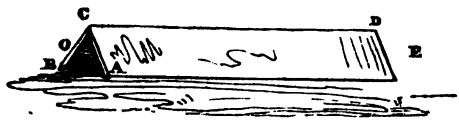
Thus, let A be the object of the space B C D, which has the same angle at C as the mirrors in the former figure; and the compound image will be the same as that shown in the circular figure, which consists of twelve repetitions of the object A, six of them direct, and the alternate six reversed.



The reflection of divergent light admits, indeed, of endless variety; and by mirrors of proper forms, the images of objects may be made to assume almost any shape. The passage of the light being always in straight lines, and the angle of reflection constantly equal to that of incidence, we can, if we are able to procure light enough from the object, and exclude other lights, calcu-

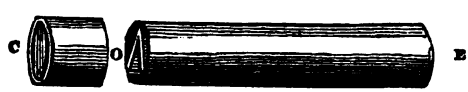
with the utmost ease the place, the form, the position, and the size, in which the image of anything shall appear to a spectator at any particular point.

Section XXXV. Description of the Kaleidoscope.



Two mirrors are joined neatly along the edge C D, so that the angle A B C is the part of a circle required. The end E is the eye-end of the mirrors, and O the object-end. The mirrors are strips of flat and smooth glass, from an inch to an inch and a half broad, and from six to nine inches long; but the size is not a matter of much consequence. They may be narrower at the eye-end than at the object-end. They may be silvered like common looking-glass, or coated on the back with strong black varnish, through which no light can ever pass. When they are set to the proper angle, the open side must be closed with any substance that reflects no light, as black velvet, or black paper that has no gloss.

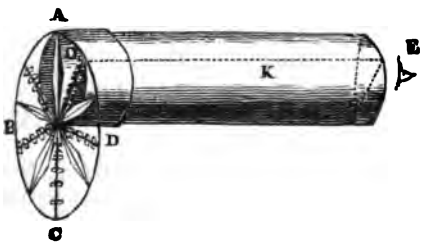
The whole is then inclosed in a case, which has a small hole for the eye at the one end, and a piece of glass at the other; and a cap, for holding the object, and having the bottom of obscured or ground glass, is placed on the object end.



E O is a representation of the case with the mirrors seen through the glass at O; the hole for the eye at the other

end is hid by the position. C is the cap, which slides on the end of the case, and the objects are contained loosely between the two glasses.

The following is a sketch of the real object, and the image, in an instrument forming five points; that is, having the mirrors at 36 degrees, or one-tenth of a circle. K is the case of the instrument, with its cap; E the place of the eye; O the opening of the mirrors; and the black dots in that space, the objects,



which may be bits of glass, chips, or anything. The small oval is the end of the instrument; and the large oval A B C D, the field of the compound image, one-tenth of which is occupied by the angular space between the mirrors; and the other nine equal segments, ranged with their points at the angle where the mirrors meet.

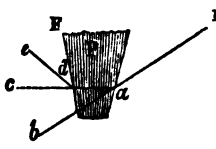
Kaleidoscopes may have more than two mirrors, though not more than four, because then the angles are too large for admitting of reflection from the one mirror to the other; and indeed four do not give handsome figures, as all the angles are right angles. The neatest are triangles; and the best of these are, the half of a square cut diagonally, and the half of a right angled triangle, cut by a perpendicular from one of the angles. The first gives an alternation of four and eight points, and the second a succession of four, six, and twelve. The figures in these are repeated several times.

Section XXXVI. Decomposition and Colours of Light.

In those actions of surfaces upon light which we have hitherto been considering, the only changes that it undergoes are those of direction and intensity. It is regarded in them all as if it were a simple substance, equally changed in the line of its motion, or in its quantity, in equal portion of space.

But light, that of the sun, for instance, is by no means simple; for we do not know of how many parts it is composed, or how unlike some of those parts are to some others.

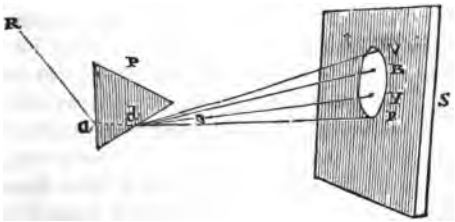
When light is made to pass obliquely through a transparent substance, the sides or faces of which are flat but not parallel, it undergoes two refractions, both in the same direction.



Let P be a piece of glass, which is thicker at the one end than the other; and let R *a* be a ray of light falling obliquely on it at *a*. If the glass were not there, it would pass on in the direction *a b*, but the glass refracts it towards the perpendicular, as in the direction *a c*. But if the direction of the emergent ray towards *c* makes less than a right angle with *d* F towards F, the ray, being refracted from the perpendicular, will have the direction *e* towards F, so that the ray will be twice refracted, and refracted towards the same hand both times.

If the two sides of the piece of glass were parallel, the emergent ray would be parallel to the incident one, as formerly explained, and the luminous point from which the ray came would still be seen, only its place would be altered a little. But though the glass is of the very same substance and polish, the obliquity of the sides of the glass, when it throws both the refractions one way, produces very different effects, effects of so very striking and extra-

ordinary a character, that we would little expect them from so very simple a cause as that of a bit of glass being in the shape of a wedge, and not that of a book. But it is very often the case in nature, that that which we would wish to know, lies in something very simple, and we neglect it. A figure will assist the explanation.



Let P, as before, be the piece of glass, R *a* the incident ray, *a d* its passage through the glass, and *e* the emergent ray after the two refractions. Then let there be a white screen or a part of the wall at S; and by the time that the emergent rays reach that, which is instantaneous to human observation, it will be shivered to atoms. No matter how slender the ray is, so that there is but enough of it to form perfect light, it will always show the same appearance.

A solid with flat and parallel faces, so as to have every where the same section or cross-cut, is called a prism; and as one with a triangular section is best for making observations on light, a piece of glass having a section like P is called *the prism.*

When the prism is held level, there is no refraction sideways; and the refraction is upward when a face of the prism is upward, and downward when a face is downward. All the parts of the decomposed light are softened off at the sides, and their ends are rounded, but the parts are well marked in pieces across the image or picture. That picture, which is, however, not a proper picture, as it is not the representation of the sun, or the sun's light,

or the prism, or the wall, or, indeed anything but itself, is called the *spectrum*, that is, the 'appearance.'

Generally, it is thus:—The end which is least bent from the original direction of the ray is red, but fading off into a dim russety colour at the very edge; and the other end is blue, but it fades off into a tinge of duller blue and dim violet. About the middle, the colour is a beautiful green, and between that and the red there is yellow.

Those are the prevailing colours, but they blend into each other by every possible gradation of tint; the red fades away from the intense red to the yellow, through all the tints of scarlet and orange; and between the intense yellow and the intense blue, there is every imaginable shade of green. The deadening of the blue toward the distant end of the spectrum, of the red toward the near end, and of all the colours at the sides, are probably owing to cross lights and secondary refractions; because they bear some resemblance to the first colour of the dawn, the last of the evening, and the general tint of very distant mountains.

It is customary to say that there are seven colours in the spectrum; but, as observed, they are innumerable, and as, except the red and the blue, all the rest can be compounded, it is possible that there are only these two—if, indeed, the yellow, from not being quite so easily compounded as some of the others, may not be considered as a third. If there are only two opposing principles in light, the one of which acting alone and completely produces red, and the other blue, we might perhaps be inclined to wonder why their united action should lighten from the red to the yellow, and deaden again from the yellow to the blue; but really all that we meet with in nature is so wonderful, when we examine it closely and carefully, that we can hardly wonder more at one part of it than at another.

When properly formed, and not disturbed by cross lights, the spectrum is remarkably beautiful; and when we find that all the colours of it can be separated out of a

thread, or scintillation of light, not thicker and probably not one-hundred-thousandth part as thick as the finest cobweb, we need not be surprised at the extreme delicacy and beauty of the colours of flowers and fruits, and feathers, and the wings of butterflies, and the wing-cases of beetles, and many other things we meet with in nature. When the prism is so made as that the light undergoes two refractions the same way, and the substance upon which it falls is capable of reflecting light without colouring it, the spectrum never fails to produce all its colours, and we can always find a point in it of any one tint that we please; so that we have only to imagine a double refraction to be produced at the surface of a substance so as to reflect to the eye one tint, and not any other, and the substance must and will appear of that tint.

It is of no consequence whether the substance be opaque, so that it reflects the whole light from the outer surface; or transparent, so that it can reflect only from the inner surface. Pure water, clear glass, and the most perfect diamond, all show the colours of the spectrum, or the prismatic colours, as they are called, from the usual way of obtaining the spectrum by means of a prism. Each of them shows the colours brilliant and distinct in proportion to its refractive power and the polish of its surfaces; and, if the surface be fine enough, it matters not though the reflecting substance be a little sphere, or, as it is called, a globule of transparent matter.

Section XXXVII. The Rainbow.

Those decompositions of light which are made by the falling drops of water during showers, are, from their being arches of circles, called rainbows; and the same names are applied to them when formed by drops of water that are at rest, or that are rising, as spray does, from waves or waterfalls.

The rainbow is usually said to consist of seven colours, and if the breadth of the bow be supposed divided into

360 equal parts, the following are the successions and relative breadths:

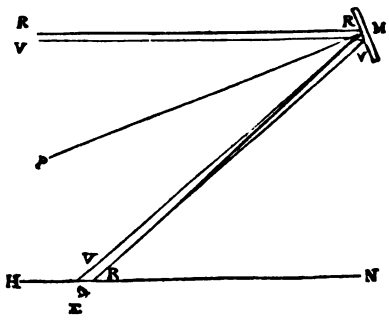
1. Red	45 parts
2. Orange . . .	27 —
3. Yellow . . .	48 —
4. Green . . .	60 —
5. Blue	60 —
6. Indigo . . .	40 —
7. Violet . . .	80 —
	Sum 360 Breadth of the bow.

In order that a ray of light may show the red colour when it passes out of water into air, it is necessary that it should undergo a refraction or refractions so as to form an angle of about 42° 2′ with the ray incident on the water; and as the violet or opposite end of the bow is more refrangible, or more easily separated, the angle required for that is 40° 17′: the difference of these, which is the breadth of the bow, is 1° 45′, or 105 minutes, or 6300 seconds, so that the angular measures of the colours are,

Red	787½ seconds.
Orange . . .	472½ —
Yellow . . .	840 —
Green . . .	1050 —
Blue	1050 —
Indigo . . .	700 —
Violet . . .	1400 —
Sum	6300 —

In order to understand how the bow is formed, we must bear in mind that the rays of the sun are parallel. Thus, in the following figure, let the sun be supposed to be just in the horizon, then any rays of solar light, as, for

instance, the ray R R and the ray V V, will be parallel to a horizontal line H N, passing through the eye of an observer at E. Then if a mirror M, is placed so to intercept the ray R R, as that such ray shall fall on it at an angle of incidence to the perpendicular P M, equal to half the angle which brings out the red colour, that is, to 21° 1′, the angle of reflection P M E, will (being equal to that of incidence) also be 21° 1′; and the reflected ray M R will arrive at the eye at E, in the direction which shows the red colour.



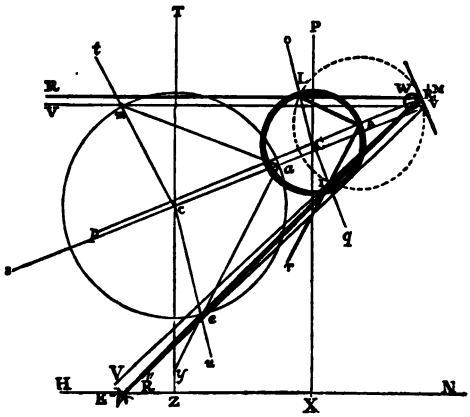
The violet colour of the ray R R will not be seen by the eye at E, for it will have a situation one degree forty-five minutes higher, as at V, because its refraction is so much more than the red. But a ray V V, a little further down, falling on the mirror, so that the angle V V E shall equal forty degrees seventeen minutes, would show the violet colour to the eye at E; and as the red and the violet are the extremities, all the other colours in their order would be shown by rays between R R and V V.

These then, that is to say, the rays R E and V E, from the mirror to the eye at E, would be the limits of the rays by which the breadth of the rainbow would be seen by that eye.

But it is by refraction, and not by reflection, that the colours are brought out; therefore, though the mirror gives the direction of the rainbow, it does not give the colours. If, however, we could find two refractions for each ray, to the same extent as the angle at the mirror, the object would be accomplished.

Thus in R′ *p*, the perpendicular to the mirror, which

also bisects or divides into two equal parts the angle at R′, take any point A (no matter at what distance from R′).



Next, about A as a centre, and the distance A R′, describe a circle (the dotted one in the figure) cutting the incident ray in the point L, and the reflected one in the point I. Draw A L, and A I; and because A is the centre of a circle, A R′, A L, and A I, are all equal to each other; ahd the angles at L and I are equal; and each of them is equal to half the angle between the incident and the reflected rays at R′ in the mirror, and the two together to the whole of that angle. If, therefore, the incident ray could be refracted at these two angles, it would come to the eye at E, and there show the red colour.

Nature accomplishes this in the rainbow.—Find C, the centre of the three points, L, A, I, draw a circle, and that circle will be the circumference of a drop of water, which sends the red light to the eye at E.

This drop is understood to be falling. The under side of it will first touch the ray, then the angle which its surface makes with that ray will gradually increase, and the

refraction diminish, till the centre C comes to the ray, in which case there will be no refraction; as the drop descends, the ray will fall upon it higher and higher, till at last it falls above the drop altogether.

In each quadrant there must be an angle of incidence capable of bringing out each of the colours; but when the light is incident upon the lower quadrant, the colours are thrown upward into the air.

In the upper quadrant, when the position answers to L in the figure, the refraction R L A on entering, and that *r* I R″, on leaving the drop, are together equal to the angle R R′ R″ at the mirror; and this is the refraction which brings out the red colour.

The ray refracted at L, falls on the posterior surface of the drop at A, at an angle of incidence to the perpendicular A C, of forty-two degrees two minutes, or to the curve, that is, to the tangent at A, of forty-seven degrees fifty-eight minutes. It therefore falls at too great an angle for passing through; and so it is reflected, at an equal angle to I in the under part of the drop. I *q* is the perpendicular at I, and as the refraction there is from the perpendicular, as much as the refraction at incidence on the drop was towards it, the direction of the ray is changed from I *r* to I E, so that the last direction is the same as that from the mirror.

The strong lines R L, L A, A I, I R″, represent the path of the red ray, from the incident sun-beam, or the sun, to the eye at E.

The circle which represents the drop of water is made large, on purpose that the lines might be seen; but as the point A might have been taken anywhere in the line R′ *p*, the size of the drop does not affect the result. It might be the small circle W near R′, or even one the thousandth part of that. There is no limit, but our ability of observing it, to the division of light, so that it may still have all its colours perfect; and as, in any drop, it is a portion too minute for being measured, that gives out the colour, a drop of one size serves as well for illustration as another.

The violet, or other extremity of the bow, would, from being more refracted, fall at V, one degree forty-five minutes higher than the eye at E; and as that portion is obtained from the ray V V′, incident on a drop a little lower down, the angle V V′ E at V′ in the mirror is one degree forty-five minutes less than the angle R R′ R″ at R′ in the mirror; of course the line V′ *s* bisecting it is inclined to R′ *p*, the line bisecting R R′ R″, the angle of the incident light and the red ray.

In V′ *s* take any point *a*, make *a m* and *a e* each equal to *a* V′, and draw the circle (the largest or light lined one). This circle represents the drop from which the violet ray is sent to the eye.

This ray V *m*, is incident upon the drop at *m*; and V *m t* is the angle of incidence. It is refracted to *a*, the refraction being the angle, *m a* V′ (to the mirror), and half the angle V′ there, that is, twenty degrees eight and a half minutes. From *a* it is reflected to *e*, and at *e* it undergoes the same refraction from the perpendicular, as it did to the perpendicular at *m*, which changes it from the direction *e y*, to the final direction *e* E, and it enters the eye at E, along with the red and all the intermediate colours of the bow.

The lines V *m*, *m a*, *a e*, *e* E (the *eye* at E and R″ here mean the same point) are the passage of the violet light from the ray V V′ to the eye; and while the violet light from the ray R R′ falls above the eye as at V, the red light of the ray V V′ which sends the violet to E (or R′) falls parallel to the strong line R′ E (or R′ R″) and thus passes below the eye at E.

It is not very easy to get an angle so small as one degree forty-five minutes, which makes only about three feet at 100 feet distance, represented in a diagram; but it is to be understood that there are two fine lines drawn from the points R′ and V′ of the mirror, that from R′ to V near the eye, and that from V′ to R″ (near the eye). Also that the strong line R′ R″, is drawn from R′ on the mirror to R″ at the eye.

The last refraction, by the drop of which C is the

centre, which is made at L, throws the red light of the ray R L, which is incident on that drop, into the direction of the strong line from I to the eye at E; and the last refraction, by the drop of which *c* is the centre, which is made at *e*, throws the violet light of the ray V *m* to the eye at E. Both drops may be spheres of water of any magnitude whatever, provided that the points L and *m* are in their surfaces, and their centres in the lines R′ *p* and V′ *s*.

The angles which the colours that are intermediate between the red and the violet form, are so small that they cannot be represented in a figure of ordinary dimensions without confusion; but they are all formed from rays lower than R R′ and higher than V R″.

In this example the sun is supposed to be in the horizon, and the rays parallel to the horizontal line H N; so that the centre of the bow is in H N, and the bow itself is a semicircle, the radius of which is the height of the bow. That is, forty degrees seventeen minutes for the inner or violet side, and forty-two degrees two minutes for the outer or red.

The angle which the incident beam of the sun forms with that reflected to the eye, in order to produce each of the colours, is constant; being, say, forty-one degrees ten minutes for the middle of the bow; and in proportion as the sun is higher above the horizon, the bow is lower, till, when the sun's altitude is forty-one degrees ten minutes, the bow is no longer visible. Thus, the height of the bow never reaches half way to the zenith; and the utmost span of it is less than one-fourth of the horizon.

But though the rainbow appears to sink down as the sun rises up, the very opposite is the fact; for we lose sight of the bow, because the rays which would form it are thrown over our heads. If the clouds be near, a man on the top of a high tower will see a much larger rainbow than one at the bottom, and one standing on a hill top, and looking down a slope, can often see a rainbow when those in the hollow can see none.

Section XXXVIII. The Secondary Rainbow.

Besides the principal rainbow, with the red outermost, which has been described, there often appears a secondary and fainter bow, with the order of the colours reversed, following the direction of the principal one, and distant from it eight degrees fifty-seven minutes. This bow, though fainter in its colours, is broader than the other, being three degrees ten minutes, while the first is one degree forty-five minutes. The extreme angle of the refracted ray with the incident, to bring out the violet colour in the secondary bow, is fifty-four degrees nine minutes, and that for the red is fifty degrees fifty-nine minutes. The secondary bow is formed by two reflections, the primary by only one. The rays fall on the under part of the drops, and are refracted upward twenty-five degrees twenty-nine and a half minutes, and then fall in the lower part of the posterior surface. From this they are reflected to the upper part in a direction parallel to that in which they entered the drop; and thus the refraction of twenty-five degrees twenty-nine and a half minutes, as they pass out of the water into air, brings them within fifty degrees fifty-nine minutes their direction when incident, which is all that is required for producing the colours.

The second reflection reverses the secondary bow over again, which brings it to the original position of the spectrum, or that with the red innermost; but as the light which forms it enters and leaves the drop at greater angles to the perpendicular than the singly reflected light, the entire bow is thrown to a greater distance.

The formation of rainbows is, when we reflect on it, a very curious matter. That portion of each drop from which all the colours must be reflected is a mere point, and not a measurable surface at all, nor would it be a measurable surface, though the drop were as big as the earth. The drop is in motion, and the rate at which light moves has already been mentioned, so that the point which

decomposes the light, and the time in which it is decomposed, are both many thousands of times less than any thing that we can separately understand or even think about. From their extreme smallness we must see many thousands of rainbows in a second, all perfectly different from each other, that is, consisting of distinct rays of light decomposed by different drops; and yet the bow is as visible, and appears to stand as firmly in the sky, as if it were an arch of solid matter, whereas, it is, in truth, nothing else than a mere spectrum or appearance.

But the bow cannot be formed without the cloud, any more than without the sun-beams; and so, considering the small space, and short time in which the same light can show its colours, the number of drops is a very extraordinary matter. But swift as the sun-beams fly, and small as are the obstacles by which they can be broken, they must yet have some room for a passage among the drops, and also for undergoing their reflections within them.

Light fogs and mists, though they appear white, and thus partially turn back the entire volume of the light, never separate it into perfect rainbows. Neither are rainbows formed in those dense and castled clouds which appear like snowy mountains on their sunny sides, or like dark rocks on their shaded ones. As little are rainbows formed in those fleecy and curled clouds which float higher in the air than the others. Indeed, a perfect rainbow is never formed, unless the drops of water are so large that they cannot be suspended in the atmosphere, but are actually falling.

Section XXXIX. Other Appearances of Light.

The different reflections and refractions of light which take place in the vapours floating in the sky, are, to say nothing of those which produce all the colours of more solid substances, very numerous and very curious. Sometimes a portion of vapour acts like a lens, and magnifies objects; sometimes it magnifies them as a mirror; and some-

times it shows a secondary image of them, in places where they do not really exist, or from which they could not be seen.

The refractive power of the atmosphere is not always the same; at one time it is greater than at others, the difference depending on variations in its temperature and humidity. Hence distant objects appear closer, or more elevated, one day than another, and the spires of churches, and the highest points of other remarkable buildings, become visible which on ordinary occasions are below the line of vision.

These appearances are most frequent near the sea, at times when the sea and land are differently heated, and they are known by the names of 'looming,' 'mirage,' and several others.

By looming, ships that are really floating in the water seem lifted into the air above it; and smooth parts of the water often lend their more powerful reflection, and the spectrum of the same ship is sometimes repeated keel to keel, or mast head to mast head,—the one sometimes detached and at a considerable distance from the other. The same sort of reflections will, in other cases, produce the resemblance of rocks or even distant cities suspended over the sea, when there is not any land in sight; and the mirage sometimes makes the sea assume the appearance of green fields, and the dry sands of the desert that of pools of water. Indeed, as we have seen that the bright colours of the rainbow can be produced in what to us is no space and no time, and as colour is all that the eye sees, and difference of colour is the only means it has of judging, we can form some notion how very little will suffice to produce any imaginable coloured appearance, be its form or its brightness what they may.

But when the beams of pure and complete light are decomposed by the refractions in the manner that has been stated, the colours are not the only results that are obtained. There is heat in the beams of the sun, and also in every other light from which a colour nearer to the place of the

red in the spectrum than the green is, can be obtained; and though, in the entire light that heat be uniformly dispersed and in proportion to the intensity of the light, it is not so when the light is decomposed.

Under common circumstances, the heat is reflected, and dispersed and concentrated by the same means as the light, but not quite to the same extent. Lenses and mirrors do not burn quite in the same proportion as they concentrate light; and though a mirror remains cold in proportion to the heat that it reflects away, it does get a little heated. These differences are trifling, and probably would never have been noticed, had it not been that some difference in the law of the action of heat and light was found out by other means, but they are confirmations of these.

Now, when the spectrum is nicely examined, by means of a delicate *thermometer*, or instrument for measuring the degrees of sensible heat, it is found that the red end of it is not only the warmest, but that the greatest heat is outside, that is, beyond the colour at the red end.

According to the most carefully made observations, if the heating power of the violet part of the blue be counted *one*, that of the green is rather more than *two*, that of the red rather more than *three and a half*, and that of the colourless part just beyond the red about *four and a half*. So that in the coloured part of the spectrum, the green is, in heating power, about midway between the red and the blue. The subject is, however, a very nice one, and observations upon it require to be made with the greatest care.

But still we may conclude that if the heat is the same with the colours, there is less of it as we approach the violet end of the spectrum, and that it is less refrangible than the colours of light, less so than even the red colour.

Heat is not the only appearance into which, besides the colours, light is decomposed by refraction. There is an energy which is most intense just beyond the blue end, and of which the intensity diminishes as the red end is approached. That energy cannot be said to be *cold;* for

what we call cold is only a lower degree of that which we call heat, but still the energy which has an opposite position in the spectrum to the heating energy, produces also opposite effects.

Heat promotes the combination of various substances with that portion of atmospheric air which is essential to vitality in the breath of animals, and which from being the basis of most substances having a *sour* taste, is called *oxygen*, or 'the sourer.' When the combination of oxygen with other substances takes place rapidly, the colour is of no consequence; it may be the pale blue of inflamed sulphur, the still paler of spirits of wine, or the most intensely white light of which we have any knowledge.

The opposite energy of the sunbeams is that of *de-oxydizing* substances,—which means taking the oxygen out of them. Thus, if vermillion, or red pigment, which is a compound of mercury with sulphuric acid (the latter consisting of sulphur and *oxygen*), be long exposed to the action of light, the acid is removed, and globules of fluid mercury are found instead of the vermillion.

In this way it is easy to account for the fading of the colours of window-curtains, carpets, and other articles of furniture, even though they may be protected from the direct influence of the sunbeams. Almost all brilliant colours used in dyeing and printing contain an *oxide* of some kind of metal, and hence we need not wonder that these should be the first to change.

The two energies also act differently on many other substances, as for instance, upon growing vegetables. The flavour or sharpness of vegetables is understood to depend upon oxygen, or substances related to oxygen; and the vegetable colours are supposed to be dependant on the same energies. In proof of this, we may refer to the globe at different places, or to the same place at different seasons. The blossoms of the tropical plants are remarkable for bright colours, and red is the prevailing tint; but as we approach the poles, the colours become paler and paler. There are very few scarlet flowers natives of England, and

in the far northern countries there are none. So, also, the brightest flowers come out in the season of greatest heat, while those which come in the early season are pale. There are also few red flowers in marshy places, and even the yellows there have a trace of green in them. The sunny and shaded sides of a peach, or of some kinds of apples, give this contrast between light and the absence of light so strongly, that the fruit is no bad miniature representation of the colours of vegetation on the globe, or for the year, if we suppose the middle of the red side to be the warmest latitude or the warmest season. The shadow of a leaf, too, will illustrate the effect of a damp and cold season upon the colour of fruit.

The texture and composition of the substance of vegetables depend not a little on the action of light; for those which grow in the dark are not only paler coloured and milder to the taste than such as grow in the light, but they are also more watery, and contain less charcoal, or carbon as it is termed. In consequence of this, the timber of many kinds of trees is softer and whiter in proportion to the shaded situations in which they grow. This does not, however, apply to pines and other trees which contain turpentine, as the light and heat soften their timber by decomposing that substance. The effect of the different ends of the spectrum upon the productions of nature is, though one of the most interesting branches of natural science, as yet only very imperfectly understood.

It will be noticed afterwards how the connexion of the red end of the spectrum with oxygen, and the violet end with hydrogen, points out a relation between light, electricity and magnetism.

Section XL. Variable Refractions.

The extreme fineness of light causes it to detect many qualities in substances which cannot be found out by any of the other tests. The most perfectly transparent glass or crystal produces a refraction, and, if the refraction be

sufficient, a particular colour is produced. The more pure and invisible the substance, the more perfect the refraction is, and the brighter the colour.

Any one who has the opportunity may see how beautifully the successive colours come out, in the cut drops of a glass lustre; and those who have not, may see the same thing in the drops on grass any sunny morning when there is dew.

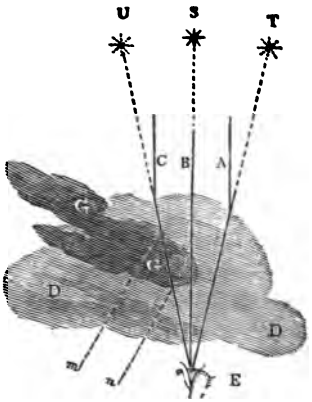
If all substances were perfectly *homogeneous*, or 'alike' in all their parts, and equally transparent, the refraction of light at passing in or out of them would be in proportion to their densities, and when the density varied, the refractive power would vary along with it at the same rate. But transparency and density have not any necessary connexion that we can discover; and, therefore, the conclusions which we can draw from the action of substances in refracting light are both partial and imperfect.

But still we do know that the density of substances is altered by heat and pressure—diminished when they are heated more or pressed less, and increased under opposite circumstances; and that, though these can take place to a very considerable extent without impairing the transparency of bodies, yet the smaller variations, which we have no other means of knowing, affect the light which passes through them. The effect on the light is also the greater, the more obliquely it passes through the substance; because the refraction is then greatest.

Under a vertical sun there is, for instance, little refraction of the solar light. It comes down in one undivided and undeviating mass, blinding by its radiance and scorching by its heat. But when the sun is low, the strata of air, which have different degrees of heat, and contain different quantities of moisture, throw the light in various directions, by their different refractive powers; and these, mingling with the reflected lights from different parts of the earth's surface, and from clouds, sometimes produce very singular images, by distorting, repeating, or otherwise varying the image that would be seen through one uniform

medium. The general principle of these refractions may be understood from the following figure:

Let E be the eye of an observer, situated in a denser medium, D D, than that through which the rays A, B, C, come parallel to each other, and let the surface of the denser medium D D be such, that the ray B falls perpendicularly upon it, so as to undergo no refraction, and the rays A and C so as to be both refracted nearer to the direction of the ray B. It is evident that the obliquity and situation might be such, as that all the three rays would meet in the same point at E.



It is further evident, that if, in that case, each of the several rays, A B C, was sufficient for producing an image of any object S, from which they all proceeded, the eye at E would see the object in the last direction of all the three rays; that is, the three images S, T, and U, of the one object would be visible, though, as there is part of the light lost at each refraction, the images T and U would be less distinct than the image S. The object S is supposed to be at so great a distance that the rays A, B, and C, all come parallel from it.

If we were to suppose another medium G G, denser than D D, to be enclosed in that, it might so happen that by the refraction of the ray C in the direction *m*, as of the ray B in the direction *n*, the refracted image U, and the true image S, might be both invisible to the eye at E; and if the medium G G were extended so far, as that the ray A also underwent a second refraction at it, the object might become wholly invisible, even though all the media occa-

sioning the refractions were so transparent, as that light falling perpendicularly upon all their surfaces, could be easily seen through the whole of them.

These refractions may be in themselves very small, and yet produce their effects at distances which are comparatively inconsiderable. The opening of the pupil of the eye, when in a strong light, is probably not above one-twentieth of an inch across; so that a refraction of one second of a degree taking place at the distance of one mile, would throw the light out of its direction. A second is an angle too small for ordinary measurement; and yet at the distance of one mile, it throws the light three-twentieth parts of an inch out of its original direction; and thus it would require three-tenths of an inch, which is a very distended pupil, and greater than that of any human eye in good health, to see the light thus refracted. In consequence of these minute refractions, the horizon (that is, the objects visible at a distance,) appears to change with every change of the weather, and even with every hour of the day, both in shape and colour.

Section XLI. Double Refraction.—Rhomboidal Crystal.

The ordinary refraction which light undergoes at the surfaces of media of different densities, is always in the plane of the incidence, that is, in the plane which contains the incident ray, and a perpendicular to the refracting surface at the point of incidence.

In the same substance, too, the index of refraction is constant toward the perpendicular, when entering the denser medium, and from it when entering the rarer; so that, if the index of refraction (which, it will be remembered, is the sine of the angle of incidence on the denser substance, which gives the sine of refraction equal to 1,) and the angle of incidence are given together with the thickness of the medium, and the position of its surfaces,

the place of the emergent ray can be calculated with the utmost precision.

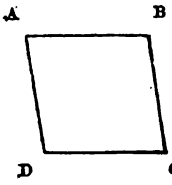
But in this simple and general theory of refraction, each of the media is considered as homogenous, or of the same uniform structure throughout its whole substance; and the light is not considered as affected by it, at any other part than the mere surface. The internal structure, in short, is not regarded as having any effect upon the light, and therefore it is not taken into the account.

There are but few natural substances which are perfectly homogeneous in any state, and perhaps there are none which are so in all states; and these differences of internal structure have some very curious effects upon light. One of these is double refraction—that is, the common refraction by the substance arising from its density and the angle of incidence on its surface, and also another refraction, of only part of the light, arising from the internal structure of the substance, and without any regard to its size or external form.

We shall be best able to simplify the principle of this second refraction, by considering its appearances in some particular substance. None answers the purpose better than that form of crystalized carbonate of lime, which is popularly known by the name of 'Iceland spar,' perhaps from being first noticed in that island. But it is a very common substance, and very large and perfect crystals of it are found in Derbyshire.

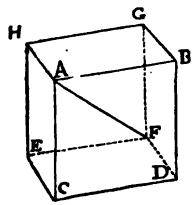
The primitive form of this spar, that is, the form into which the pieces, whatever may be their shape when found, can easily be split, is that of a solid bounded by six faces, in the form of rhomboids, or lozenges, having their opposite sides equal and parallel, but two of the opposite angles greater than right angles, and the other two just as much less.

The annexed figure is the shape of any of the six faces of the perfect crystal.



The angles at A and C are each equal to 105 degrees 5 minutes, and those at B and D to 74 degrees 55 minutes. These four are together equal to 360 degrees, or two right angles; and one large and one small one are equal to 180 degrees.

In this figure the four sides are all equal, and this may be considered as the perfect form of the crystal; but it is not necessary that it should have this form, for it can be divided parallel to any of the faces, so that the length, the breadth, and the thickness, may all differ. Still, whatever may be the length, the opposite sides, angles, and faces, are always equal; and so are the opposite solid angles.



The annexed figure, in which the faces turned to the eye are represented by the black lines, and the faces turned from the eye by the dotted lines, will give a notion of the perfect transparent rhomboidal crystal.

Upon examining this figure it will be seen that the six faces have altogether twenty-four plane angles, twelve of them 105 degrees 5 minutes each, and the other twelve, 74 degrees 55 minutes each. The eight solid angles are made up of these twenty-four; and in the substance in question three of the large plane angles are ranged round the point of the solid angle at A, and other three round that at F.

Six out of the twelve larger angles are thus disposed of in forming two of the solid angles, and of course there remain only one large angle and two of the smaller ones for each of the remaining six solid angles.

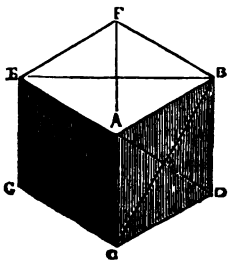
Two of the solid angles, A and F opposite to each other, are thus composed of equal plane angles of 105 degrees 5 minutes each; and the remaining six of unequal plane

angles, namely, one of 105 degrees 5 minutes, and two of 74 degrees 55 minutes. The first two are regular, or alike in all the three faces which meet at the point, but the remaining six, though all equal to each other, are irregular. The former are the obtuse, flattened, or blunt solid angles; and the line A F joining them is the shortest line that can be drawn from angle to angle through the centre of the crystal. All the other lines that can be drawn from angle to angle through the centre, are equal to each other, but any one of them is longer than A F.

A line which passes through the centre of any solid is called the *diameter* of that solid; A F is, therefore, the shortest diameter of the crystal.

All the faces make equal angles with A F; and upon whatever face the crystal is laid, A F always stands at the same angle to that face. Thus, without any reference to the effect of the crystal upon light, the line A F has properties which belong to no other line in the crystal; it is thus called the *axis* of the crystal, because the crystal is, as it were, formed round it. The following is the crystal with the axis turned directly to the eye.

It must not be supposed, however, that a crystal with the same faces could have only this form; for three of the smaller plane angles might have been arranged round two opposite solid angles; and then there would have been two of the larger, and one of the smaller to each of the remaining solid angles.



In that case, the two regular solid angles would have been sharp, or acute, and the axis would have been the longest diameter; but still all the faces would have made equal angles with that axis. There are some natural crystals of that form; but a particular account of them is not necessary.

Section XLII. General Laws of Double Refraction.

Before proceeding to point out how the phenomena of double refraction are developed, it may be proper to state, that in all crystals that have one axis—as the Iceland spar, which has its axis the shortest diameter, or ruby, which has the same faces and angles, but its axis the longest diameter,—the second, or extraordinary refraction has always reference to that axis; all the phenomena of that refraction being the same as though some power emanating from the axis had produced the extraordinary refraction, by separating a portion of the light from the original ray in its transmission through the crystal, and attracting it towards the axis, or repelling it from it.

Sometimes the extraordinary refraction is *negative*, or a deflection farther from the axis, as an Iceland spar; and sometimes it is *positive*, or a deflection nearer to the axis, as in common quartz crystal; but it is always with the axis that the angle of extraordinary refraction is made.

If the axis is in the plane of incidence, both refractions are in the same plane, and the extraordinary ray is farthest from the perpendicular when negative, and nearest to it when positive.

If the axis is oblique to the plane of the incidence, the extraordinary ray is turned out of the plane of the ordinary refraction,—from the axis, if negative; and toward it, if positive.

If the plane of the incidence is at right angles with that of the axis, the incident ray must evidently be at right angles to the axis, whatever the angle of incidence on the surface may be. It is found that, in this case, the refraction of the extraordinary ray follows the same law with that of the ordinary ray.

If the plane of incidence is parallel to the axis, there can, of course, be no extraordinary refraction, as the tendency to, or from, the axis is equal in opposite directions, whatever may be the angle of incidence on the surface.

We may readily foresee of what nature the refraction

of a ray incident in any direction upon a crystal will be, by drawing through the point of incidence a line parallel to the axis of the crystal, and considering the deflection which would be produced in it by a positive or negative force (according to the nature of the crystal) emanating from that line.

In these short enunciations, the *axis* is used as signifying the axis of the crystal, and also all lines parallel to that axis.

Section XLIII. The Rhomboid of Iceland Spar.

If one of these rhomboidal crystals of carbonate of lime, or Iceland spar, be laid upon its natural face on paper, upon which there is one line or one dot, the line or the dot will be seen double; and if a small pencil of the light of the sun falls on the crystal, and is received on paper on the other side, it also will be seen double.

If the eye is placed perpendicularly to the upper face of the crystal, or if the light falls perpendicularly upon it, the separation of the two images will remain the same in whatever direction the crystal is turned round; and if it be the regular or perfect crystal, with all its faces of the same size, it will be of no consequence on which side the crystal is laid on the paper, or on which face the light is made to fall.

The double images which are thus produced are not coloured, as the different parts of the spectrum and the rainbow are when separated by the prism or the raindrop; they are both white light when the light of the sun is transmitted through the crystal, and they are both images of the dot or the line on the paper, in its natural colour.

The light, therefore, considered as white or entire light, is, in these cases, divided into two distinct portions, one of which obeys the ordinary law of refraction, and the other does not, but follows the particular law of the crystal.

That pencil or position of the light which follows the common law of refraction, is, for the sake of distinction,

called the *ordinary ray*, and that which follows the particular law the *extraordinary ray*.

If the crystal is placed over a dot, and the eye exactly perpendicular above it, the ordinary ray suffers no refraction, and the dot is seen in the very same situation, as if the crystal were not there. But even in this case, the extraordinary ray is refracted; so that, if the eye is kept steady, and the crystal turned round on the dot as a centre, the second dot performs a revolution round it, as in a small circle.

If the eye is so placed that the line from it to the upper surface of the crystal falls obliquely on that surface, the ordinary ray from the dot is bent farther from the perpendicular, and the dot appears farther removed in the oblique direction, and raised a little higher, as is the case with the under end of a stick when it is seen obliquely, with part of it in the air, and part in water.

The angular distance of the two rays, when the ordinary one falls perpendicularly on the face of the crystal, and is, of course, not refracted, is about six degrees twelve minutes.

If the crystal, when viewed obliquely, is turned round on the dot, the peculiarities of the double refraction begin to be developed. The ordinary refraction is always in the same vertical plane with the line joining the eye and the upper face of the crystal; but the extraordinary refraction sometimes is, and sometimes not.

If the position of the crystal is such, that the vertical plane in which the eye is situated passes through the two obtuse angles of any of the faces, the ordinary and extraordinary refractions are both in that plane; but the difference between them varies with the obliquity of the eye and the position of the crystal.

If the obtuse solid angle is turned toward the eye, and the obliquity such, that the ray of ordinary refraction is parallel to the axis of the crystal, there is no extraordinary refraction; but if the acute angle, that is, the solid angle, which is formed of one of the large angles and two of the

small ones, is turned directly to the eye, then the extraordinary refraction is the greatest possible that can happen under that obliquity.

If the crystal is turned round from the first of these positions gradually to the second, in the direction from left to right, the two images of the dot will begin to separate, by the extraordinary one being thrown to the left, and gradually round to the direction opposite to the eye, which it will reach after half the revolution, that is, when the acute solid angle is nearest the eye. Continue the revolution, and it will return by the right side; and when the entire revolution is completed, it will again coalesce with the image of the common refraction.

From these facts it is evident that the double refraction is not two refractions of the same ray or pencil of light, such as would take place at the surfaces of two media of different refractive powers—as if the light passed from air into water, and then from water into glass; but that they are distinct, the one being produced at the surface of the crystal, and having reference only to the angle of incidence upon that surface, as if the crystal were homogeneous; and the other having reference to the plane passing through the two obtuse angles of the face of the crystal, or any plane parallel to that.

The bisection of any of the faces through both its obtuse angles gives the same result, so that though the planes passing through all of these may be considered as *principal sections* of the crystal, yet they must all be referred to their common section,—that is, to where they cross and divide each other into equal parts, and that is evidently the axis of the crystal, or the line joining the two obtuse solid angles.

All crystalized substances have this property in a greater or less degree; and some solids, as well as some liquids, in which the crystaline structure cannot be traced by any of the common means, have it also. It is barely, if at all, observable in glass which has been carefully annealed by cooling it very gradually; but even in this glass it may

be produced by heating it to the melting point, and then cooling it rapidly.

In some substances, the extraordinary refraction is toward the axis, and not from it, as in the Iceland spar, and these are said to have *positive* double refraction; but in the greater number the extraordinary refraction is *negative*, or from the axis.

Some have more than one axis, and in some of these the refraction is positive to one axis and negative to another; and this gives rise to resulting axes, at which the positive and negative refractions exactly balance each other, and there is of course no double refraction either way when the light is parallel to the resulting axis. Some further illustrations of the laws will be given in a future section.

Section XLIV. Double Refraction of the Eye.

The property of refracting doubly, in all probability extends to every transparent substance that has what may be called an internal *structure*, though in ordinary states different axes may so neutralize each other that no double refraction shall be perceived.

These axes are lines making angles with each other; and each axis exists in all parts of the substance. They will then produce different effects, as the light falls differently on them. Thus, if they are at right angles, the whole refraction of each will be shown when the light falls parallel to the other; and if they both refract positively or negatively to the same extent, the one will destroy the other, when the direction of the ordinary ray bisects the angle between them. If they have both the same kind of refraction, but in different degrees, the neutral line will divide the angle they make with each other, in the proportion of the sines of their several double refractive powers.

From these observations it is easy to see how, if the directions of the axis, and the kind and degree of extra-

ordinary refraction at each are found, all the other particulars may be determined; it being borne in mind that these axes, how many soever there are of them, are all lines making angles with each other at a point, which point may be anywhere within the substance.

There is a doubly refractive power in the human eye, though in which part it is not easy to say—perhaps it is in more parts than one; and it is certainly developed by more than one set of circumstances.

In certain fatigued states of the eye, and these are always accompanied by a suffused state of the vessels, (for the effect can be removed, or at all events mitigated by cold and stringent applications, such as a solution of common salt in water,) there is an indistinct and very troublesome second image, imperfectly separated from the other; as if, for instance, the letters of a book, or the characters in writing, were casting little shadows.

This cannot arise from any want of parallelism in the axes of the two eyes, for the closing of one of them does not remove it; neither can it be from the eye not bringing the rays to a proper focus, because, in that case, the indistinctness of vision does not appear as a shadow on one side of the proper image, but as a mistiness all round it.

Most people must be aware that if one of the eyes be pressed to one side, the image of any object, as for instance that of the flame of a candle, will be seen double, the image which is seen by the eye that is pressed being removed from the other. But it may not have been so generally observed, that if the pressure on the one side of the eye is resisted by a little pressure on the other, the image seen by that eye will be partially divided into two; and this can have no connexion with the obliquity of the axes. It is not easy to separate the two images even of a small flame completely; but it is very easy to separate the points. Many curious optical facts may be discovered by experiments on the eyes, without any other apparatus.

Section XLV. Structure of Crystals—Principal Section—Axis.

No crystal which has sensible magnitude, how small soever that magnitude may be, can be considered as a perfect whole, in the same sense as we consider a plant or an animal. The plant or the animal is made up of parts or organs, all of which are necessary to the others. When these parts are once separated, there is an end of the organized being; and there is no property observable in the separated parts by which they can be again organized, so as to recompose the plant or the animal.

Crystals have often beautiful forms, and every species of crystal has a peculiar structure. The tendency to assume that structure is inherent in its substance as matter, and is always exerted, unless when hindered by something else.

When we come to consider the action of heat, we shall have to say something more about the formation and structure of crystals; but it is necessary for every one to have clear notions of the distinction between the organized and the crystaline structure.

It is probable that what may be called the elementary or primary state of all matter when solid, is that of crystals. All rocks are collections of crystals, though in some the individual pieces are too small to be seen by the eye. Water becomes crystalized in snow or ice, whenever the temperature is sufficiently low; and such is its tendency to crystalize, that the small portions which get into the fissures of mountain rocks during the summer, break those rocks in pieces when the winter cold sets in. Metal pipes with water in them are also liable to burst if that water be allowed to freeze.

Now, as the tendency to assume a particular form is inherent in the substance as matter, and not as a particular arrangement of matter (for it is the cause of the arrangement, and cannot therefore also be the consequence of it), it follows, that it must be common to all parts of

any crystal. Any crystal is divisible beyond the limits of our perception, into other crystals of the same shape, and possessing, in proportion to their quantities of matter, exactly the same properties as the larger crystal, which their aggregate forms.

The rhomboid of Iceland spar may be easily divided in a plane parallel to any of its faces; and thus it may be divided into an unlimited number of crystals—at least into a number, of which our being able to see them is the only limit. Each of those small rhomboids divided as far as the best eye, the finest miscroscope, or the boldest imagination can carry the process of dividing them, has the very same properties as the largest rhomboid which we can see or imagine.

Each has the angles of its faces, and its solid angles, formed by the union of three of these, exactly the same, and the only difference is in the lengths of the boundary lines.

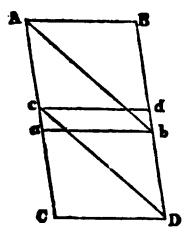
A plane which, meeting any of the faces at right angles, divides the obtuse angle of that face into two equal parts, is always the principal section of the rhomboid. As the rhomboid has six faces, which are two and two opposite and parallel, the plane of the principal section may be in three directions, each of them bisecting one of the obtuse plane angles that form the obtuse solid angle.

These planes divide the space round the point of the solid angle into three equal parts; and thus they are inclined to each other at angles of a hundred and twenty degrees. But as, upon examining the rhomboid, it will be seen that the angular edges at each of the obtuse solid angles are opposite to the middle of the faces at the other, there are really six positions of the principal section of the rhomboid, all meeting in the axis, and making equal angles, that is, angles of sixty degrees, with each other around it.

These planes pass through the six acute angles of the rhomboid, all of which are equally distant from the axis and from each other, though three of them are nearer to

the one pole of the axis, that is, to one of the obtuse solid angles of the rhomboid, and three of them are nearer to the other; the plane passing through the three acute angles nearest each end, would cut the axis one-fourth of its length from that pole.

It is only when the rhomboid is perfectly regular, that is, when all the edges are of the same length, that the same axis passes through both obtuse angles of the crystal. For if the dimensions of the face be greater one way than the other, as in the figure A, B, C, D, the axis through the angle A will be parallel to that through the angle D, the first will be in the axis of the part A B, *a b*, and the second in that of the part C D, *c d*.



As the crystal admits of unlimited division, the principal sections or planes of the axis are also unlimited; but those that pass through the same face all have the same position—parallel to each other, and meeting the edges at angles of fifty-two degrees thirty-two and a half minutes.

The true meaning of the axis, therefore, is one constant direction, which runs through all parts of the crystal; and the second, or extraordinary refraction, has reference to that direction, and not to the external shape of the crystal. For the crystal may be formed into a flat table, a lens, a sphere, a prism, or any other figure; and when so cut, the ordinary refraction of light incident upon it will follow the law of its external figure, as if it were a homogeneous substance; but the extraordinary refraction will follow the law of the axis,—or the compound law resulting from the several axes, if there are more than one.

The Iceland spar has but one axis; its double refractive power is considerable, and the extraordinary rays are thrown from the axis, so that it is among the best substances from which to get a simple view of the matter.

It is, then, to be understood that the extraordinary

refractive power is a tendency or direction given to a certain part of the light, and that that tendency begins at parallel lines in the direction of the axis. Its effect is to throw that part of the light upon which it acts either farther from the axis, or nearer to it. In the first case, the double refraction is, as has been hinted, called *negative*, and the unknown *power*, or property (we know nothing of *powers* but their *effects*), is called a *repulsion*, that is, 'a driving away.' In the second case it is called *positive*, and the unknown power or property is called an *attraction*, that is, 'a drawing together.' The Iceland spar of which so much has been said, is an instance of the repulsion; and common rock crystal is an instance of the attraction; but why these should be different, or why they should exist at all, we are unable to find out.

Section XLVI. Simple Laws and Modifications of Double Refraction.

It will be borne in mind, that when the surface upon which light falls obliquely is horizontal, the common refraction is always in the vertical plane; and that when the principal section is in the vertical plane also, the extraordinary refraction is in the same plane. But the appearance of the extraordinary refraction is modified by the angle which the incident light makes with the direction of the axis. If it is parallel to that direction, there is no extraordinary refraction.

This is very easily illustrated by cutting or grinding off a portion of each of the obtuse angles of the crystal, so that the two new faces may be equilateral triangles. If the crystal is laid upon one of these new faces, so as to cover a dot on paper, that dot will be seen only single by an eye directly over it, through whatever part of the crystal it may be viewed.

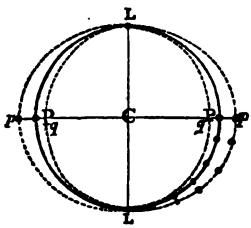
On the other hand, if two flat faces are cut or ground, on two of the opposite acute solid angles of the rhomboid, so that those two new faces are parallel to each other, and

their planes at right angles to the axis, the refraction of the extraordinary ray will be the greatest possible; and it will be such, that if the ordinarily refracted ray be thrown to the distance of sixty degrees from the perpendicular, the extraordinary one will be thrown to the distance of about sixty-seven, or seven more.

When the plane of incidence is thus at right angles to the axis, both the refractions are in this plane. If, when the rhomboid is placed in this manner, it is turned round on the centre of the face upon which it lies, there will be no change in the places of the two images of a dot seen through it; but if the light be made to revolve round in a circle over the rhomboid, both images will revolve round the centre of the crystal, as if they were on the same radius, and the extraordinary one at the greatest distance from the centre.

If the rhomboid be first placed with the light falling on it parallel to the axis, and then gradually turned round, so that the direction of the axis and that of the incident light gradually make a larger angle with each other, the images produced by the ordinary and the extraordinary rays will gradually separate; but the separation will be directed to a centre. If the angle of incidence upon the face of the rhomboid, either the natural face, or a face prepared on purpose, is the same throughout the whole revolution; the path of the ordinary ray will be a circle, and that of the extraordinary ray an ellipse, in contact with the circle at the two positions parallel to the axis at its two extremities, and diverging without it to a maximum at the perpendiculars, where the half diameter of the ellipse is to that of the circle as sixty-seven to sixty nearly. That is to say, if the thickness of the crystal is one inch, and the angle of incidence such that the refraction throws the ordinary ray six-tenths or sixty-hundredth parts of an inch from the perpendicular to the surface, the images of extraordinary refraction when at right angles to the direction of the axis, would be sixty-seven hundredth parts of an inch without the circle.

Thus, if C were the centre, L L the direction of the axis, and P P the perpendicular to that direction, the circle L, P, L, P, would be the *locus*, or place of the successive images of ordinary refraction during a complete revolution; and the ellipse L *p* L *p* would be the locus of the images of extraordinary refraction; and, if the object were a dot, the two sets of images would gradually separate in the progress from the parallel to the perpendicular, as is seen in the dots, on the circle and the ellipse, from L at the bottom to P and *p* on your right hand.



The proportions shown in the above figure are nearly those for Iceland spar. If the substance had more double refractive power than that, the ellipse would of course have more elongation at *p* and *p;* and if it had less, the ellipse would have less elongation at those points.

If the double refracting power is positive, or an attraction toward the axis, then the path of the extraordinary ray during a revolution will be the ellipse L *q* L *q*, which has its longest diameter coincident with the circle at L and L, and falls within it and *q* and *q;* and the distance which *q* and *q* fall within L and L, will increase with greater double refractive power, and diminish with smaller, as in the former case.

SECTION XLVII. EFFECTS OF CONTIGUOUS RHOMBOIDS IN DIFFERENT POSITIONS.

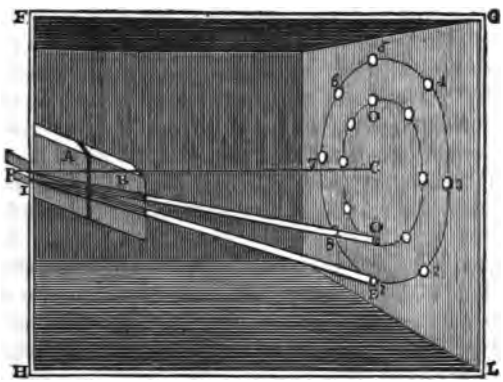
IF a pencil of light is admitted successively through two or more rhomboids of Iceland spar, the results vary in a very remarkable manner with the positions which these rhomboids have in respect to each other.

If they are placed so that their corresponding faces, and consequently their axes, are all parallel to each other,

the effect is the same as would be produced by one rhomboid of the same thickness as them all.

Thus, let A and B be two rhomboids, so placed as to have their faces parallel, and to turn round on the face toward the wall F H, in a little frame, which is not shown in the figure. The turning to be the same as if it were round the perpendicular P C as an axis; so that four of the faces may be at right angles to this perpendicular during an entire revolution.

Let a beam of light (the only light admitted into the little apartment) entering by the short tube at I, fall on the rhomboid A.



Then, if the two rhomboids are in the position shown in the figure, I O will represent the ray of ordinary refraction, and I E that of extraordinary, or the spots O and E will be shown on the lower part of the opposite wall at the position 1.

Turn the frame with both rhomboids one-eighth of a revolution (forty-five degrees backwards at the top,) or, which is the same, forwards at the bottom; and the spots will be moved to the position 2. A second eighth will bring them to 3, a third to 4, and so on, till, after an

entire revolution, they will be brought to the first position at 1.

If the wall or screen G L, on which the spots are, is parallel to those faces of the rhomboids on which the light from I falls, the spots in their revolutions will form perfect circles round the centre C; and their appearance will be the same with reference to that centre and to each other, at all parts of the circles.

If the rhomboids are of equal thickness, the spots will be twice as much separated by the two as by one, but the whole of the separation will be confined to the pencil I E, and the other I O will follow the law of ordinary refraction.

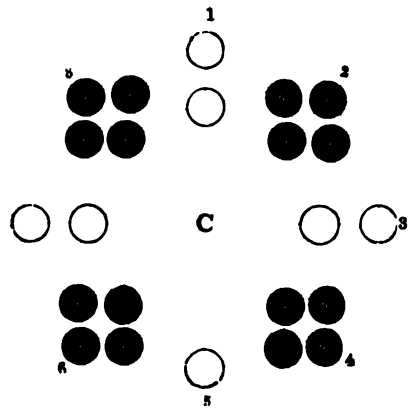
Hence, when successive double refractions take place in the same plane, it is the same portion of the original light which undergoes extraordinary refraction at each of them.

The more surfaces the light passes through, whether it be the direct light, or a reflected image, the fainter it becomes, because some of it is reflected, some dispersed, and some absorbed at every surface; but still, so long as any continues to pass through by double refraction in one plane, it follows the law which has now been stated.

If, however, one of the rhomboids is turned round upon the other, so that its axis makes a succession of different angles with the axis of the other, the result is very different.

In that case the second rhomboid separates both rays of the first into an extraordinary and an ordinary pencil; and as this second division of the rays forms, in the course of a revolution, all angles with the first, the images are continually varying. Sometimes there are only two, sometimes there are four, and sometimes again there is only one. As these images are not all thrown to equal distances from the perpendicular to the rhomboid A (in last figure) which remains stationary, it is not easy to represent them accurately on a wall or screen as in that figure; but a reference to it, and to the following, will give some notion of the effect.

Let 1 be the position in which the axes of the two rhomboids are parallel, and there will appear two spots as formerly. Turn the second rhomboid upon the first, and a faint spot will appear midway between the two, which will gradually get brighter and separate into two; and when the position 2 is arrived at, the four spots will be of equal brightness, only the two that came last into notice will be nearest each other. After another eighth, the first will gradually become fainter, and the two that remain will be nearer to each other than the two at 1. Continue turning, and these will separate, and other two gradually appear between them, till at the position 4, all the four will be again of equal brightness. Still turn, and the two middle ones will become brighter and unite in one very bright one at 5, all the rest having disappeared.

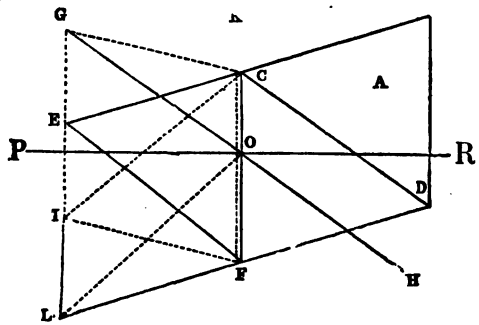


From 5 round to 1, is just the reverse of the former half revolution; and when 1 is arrived at, the two spots appear the same as at first.

It is to be borne in mind that these images are not thrown round in a circumference as they are drawn in the cut, but that the common centre of them all is the centre of

the single one at 5; and they are placed in a circle for the convenience of referring to the turning of the second rhomboid.

Let us now see how we can explain these appearances; but for that purpose it may not be amiss to introduce another diagram.



Let A be a section of the first or fixed rhomboid, and the black lines E K F L a section of the moveable one in the separation, when the axes C D and E F of the two are parallel. Also let P R be the perpendicular on which the second rhomboid is turned round, and O the point in the contiguous faces which is the centre of revolution.

As C D and E F are parallel, G H can be drawn through O parallel to them. Turn E K F L round upon O, so that L may coincide with G, and F with K, as in the dotted rhombus. I K is now the axis of the second rhomboid, and O L the parallel to it through O; the angles which O G and O L make with the perpendicular are equal, each of them being equal to half, and the two to the whole, of one of the acute angles of the rhombus. They are also in the same plane with each other, and with the perpendicular, and therefore, any double refraction which takes place at either of them must also be in that plane.

But the double refraction in the rhomboid is always

from the perpendicular toward the acute angle. Therefore, any ray of light falling upon the face from the direction R, will have its extraordinary refraction toward the angle F in the first rhomboid, and toward the angle L in the second; and, therefore, will be one double refraction equal to the sum of these, as in position 1, in the preceding figure.

But when the second rhomboid is reversed, as in the dotted lines, the double refraction in that will be as much thrown toward the angle G, as it is thrown toward F in the first rhomboid, and as they are equal and in opposite directions, the one must undo or destroy the other, and there can be only one image, and that from ordinary refraction, as at 5 in the former figure, page 146.

When the plane of the principal section of the second rhomboid is at right angles to that of the first, the extraordinary ray from the first is not transmitted; and so at those positions which answer to 3 and 7 in the former figure, there are only two images in the plane of the principal section of the second rhomboid.

In those parts of the revolution which lie nearest to 1 and 5, the double refraction from the second rhomboid begins to appear; and at those near 3 and 7, that of the first begins to appear; and in the positions 2, 4, 6, and 8, which are at angles of forty-five degrees, both refractions are equal; only that which is produced by both throws the two images farther apart than that which is produced by one only.

SECTION XLVIII. POLARIZATION OF LIGHT.

FROM what has been stated in the last section, it will be seen that after light has been divided into an ordinary and an extraordinary part, by double refraction, the properties of those parts are no longer quite the same.

The ordinary ray, which has been affected only by the angle of incidence, and the common refractive power of the medium, considered as a homogeneous substance, is

altered in nothing but its direction and intensity. But the doubly-refracted portion—that which has been repelled from, or attracted to, the axis of the crystal, by the internal or structural repulsion or attraction, has got a tendency to the plane into which that force has turned it, so that it cannot appear by another refraction in a plane at right angles to that one. It, therefore, becomes gradually fainter and fainter, the more it is turned out of the plane in which it was separated from the ordinary ray, and vanishes when it comes to the cross direction.

Such light is not improperly called *polarized*, because it is directed to or from a particular line or direction—that of the axis of the crystal.

Double refraction by transmission through substances which produce this effect is, however, only one of the means by which light may be polarized; and probably every change which is given to the direction of light, by the action of the surfaces of reflecting substances, or the refraction of transmitting ones, occasion some degree of polarization toward the plane into which the rays are bent. When light is reflected at a small angle to the surface, the polarization becomes apparent; and so also when it passes through a sufficient number of thin plates.

In many cases, the refractions which produce polarization, and those which produce decomposition of the light wholly or partially into the colours of the spectrum, are often so curiously blended, that the results are very singular, and the way in which they are produced very difficult to describe, or to represent by diagrams.

In cases where the light from the posterior surface is polarized, it is always the reflected portion that is so, and when the effect is produced by transmission, it is the transmitted light. The portion of the light which is dispersed, or otherwise disposed of, is coloured or not coloured, or coloured of various tints, according to circumstances. The polarized light has always reference to some line, or lines, which cross the spectral image; and when these intersect rays of dispersed and coloured light, they

often produce singular figures. One or two of the most general and simple facts are, however, all that we can with propriety mention.

The first of these is the identity of doubly-refracted light, and light polarized by reflection from the posterior surfaces of transparent media; and this will at once appear by introducing two figures, and comparing them with those given in the last Section.

Section XLIX. Light once Reflected.

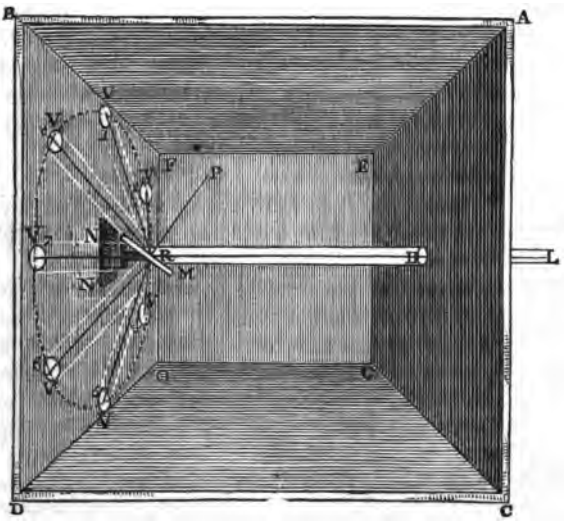
We may repeat as a fact to be borne in mind, that when light is bent at any surface, whether by refraction or reflection, the ray which leaves the surface is always in the same plane with the ray that falls on it. If the surface itself be a plane, a straight line can always be drawn across it at right angles, both to the incident ray and the refracted or reflected one; and if the surface be a curve, a tangent can be drawn at the point of incidence perpendicular to both rays.

This is self-evident; for light proceeds in straight lines; a refraction or reflection is an angle; and any two straight lines making an angle are in the same plane, whatever that angle may be.

Well, let AB, CD, EF, GO, (see page 151,) be a perspective representation of a darkened room, into which a beam of parallel light L R, from a luminous body without, is admitted through a round hole H in the wall A C G E, toward your right hand in such a direction as to be at right angles to the wall through which it passes, and also the opposite wall, and parallel to the floor, the roof, and the wall E F G O. That beam of light, if it met with no interruption, would fall at the centre of the dotted circle, v. v. v. v. v. v. v. on the wall toward your left hand; and if it met with no disturbance, it would form there a spot of light, corresponding in size and shape with the hole at which it entered.

Let there now be fastened over the dotted circle a

socket N N, in which a piece O R, placed in the direction of the line R L, or the axis of the beam, could turn round, as if R L were its axis. To the end of this piece fasten a bit of plane glass, horizontal in one direction, but sloping in the other, so that the line P R, perpendicular to its surface, make with the axis L R of the beam of light, an angle of incidence L R P of not less than about fifty-eight degrees, or not more than thirty-two degrees, with the surface of the glass; the greater part of the light will be then reflected by the surface of the glass; and as the angle of reflection of the axis of the beam P R 1 must be equal to that of incidence L R P, the axis of the beam must fall at the dot at 1, and the beam itself form the circular spot of white by which the dot 1 is surrounded.



Now, turn the piece O R in the socket backwards one-eighth of a revolution toward the wall E F G O, and the reflected beam will fall on the white circle 2. Turn the glass another eighth, and the beam will fall on the spot 3,

which in the figure is hid by the piece that supports the glass. Continue to turn six more eighth parts of a revolution, and the beam will fall in succession on the positions 4, 5, 6, 7, 8, and lastly 1, the first position.

But in passing from the position 1 to that position again, the reflected beam has travelled along the whole circumference of the dotted circle; and if the piece which supports the glasses were turned round with sufficient rapidity, the illuminated part of the wall would seem an entire ring, and the light a cone, having its apex at E, and its base the ring on the wall.

In all these positions, however, and in the ring itself, the light would be everywhere the same in intensity, and there would be nothing to distinguish any one side of the spots from another.

In this case there is no apparent polarization toward any particular line in the circle round which the spots are ranged, any more than when the two rhomboids are turned round together with their axes parallel, the divergence of the extraordinary ray had reference to any particular line in the circle.

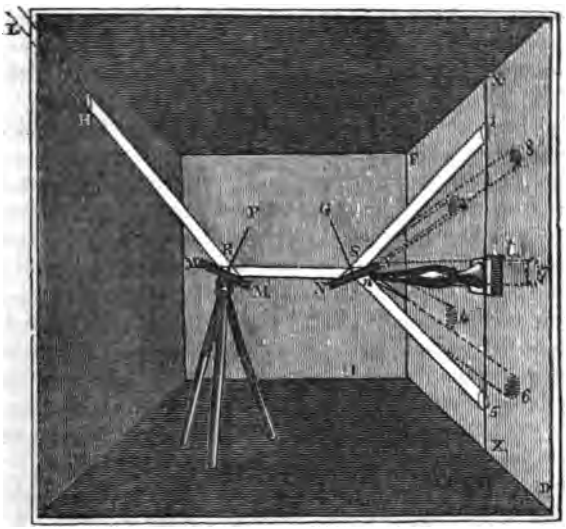
But, just as was the case with the ray of extraordinary refraction in that instance, the reflected light is polarized in all cases in which the incident light falls on the surface of the glass at an angle of about thirty-two degrees, or where the light, reflected from the surface of the glass, makes an angle of thirty-two degrees with the surface, or a hundred and sixteen degrees with the incident light.

The plane toward which it is polarized is that of the two rays, the one incident upon, and the other reflected from the glass; and, in like manner as the two rays which, in the former instance, had been separated by double refraction in the plane of a principal section of the first rhomboid, could not be so separated in a plane at right angles to that, so as to become visible, so also light, which has been polarized by reflection from the first glass, cannot be again polarized by reflection in another plane at right angles to that.

There is, therefore, a very great similarity—a similarity amounting almost to perfect identity, between the refraction in the crystal which produces the double image, and the reflection at the surface of the piece of glass. A figure will make this plainer.

Section L. Polarization by Reflection.

Let the figure represent the interior of a room as before; and let L R be a beam of light coming from a luminous



body without, passing through the hole H, and falling on the piece of glass M M, at an angle of about thirty-two degrees with the surface. If this beam met with no interruption, it would fall upon the wall F D, and form, at the centre of the dotted circle, a spot, similar in size and shape to the hole H.

Upon this centre let the socket *t* be fixed, with its axis

in the direction of R S, the axis of the beam, reflected from the surface of the glass M M, and let the piece *n* be fitted to turn in this socket, and bear the piece of glass N N, upon which R S falls, at an angle of thirty-two degrees with the surface. The lines R P and S Q are the perpendiculars to the pieces of glass at the points R and S.

Though the beam L R comes slanting into the room in the one direction, it must be understood to be vertical in the other; so that if a plane were made to touch H R and R S throughout their whole length, it would meet the opposite wall in the line X X. X X is therefore the plane of the original ray and the first reflected one.

Let the piece of glass N N, be so placed that though it be slanting in one direction, it is horizontal in the other; and the beam S 1, which that glass reflects, will be in the same plane with H R and R S; and will form the spot 1, bisected by the line X X.

In this situation, the spot 1 will, with the exception of what is lost by dispersion and absorption at the surfaces of the two glasses, exhibit the same light, as the hole H, or as the glass M M, would have thrown upon the wall at the centre of the dotted circle.

But if the support of the glass N N be turned in its socket, in the same manner as the glass M M was in the former instance, the effects will be very different from what they were.

If the glass is turned one-eighth of a revolution, and the reflection brought to the position of the spot 8, that spot will be only half as bright as the spot at 1. [The reader must *imagine* the positions from 1 to 5. 2 is opposite 6, 3 opposite 7, and 4 opposite 8.] If it is turned another eighth, and the spot brought, as it would be, at 3 (which is hid by the socket of the glass) the spot will be very faint; or if the angle of the first incidence and reflection has been that of complete polarization of all the reflected light, which, for glass, may be estimated at thirty-one degrees forty-seven minutes with the surface of the glass, the spot will vanish altogether. Continuing to

turn, the spot will begin to revive as the position 4 is approached. At 5, it will be again bright as at 1. But if the turning is continued, it will fade away towards 6, vanish at 7, revive again at 8, and be as bright as the original spot when it comes to 1.

Comparing the effects in this figure, with those in the figure at page 146, in which one rhomboid was turned round upon the other, so that the planes of their principal sections or axes made different angles, it will be seen that, in as far as polarization is concerned, they are exactly the same. When the two refractions, or the two reflections, are in the same plane, the light is polarized to that plane by both; and were it not that it becomes fainter by the dispersion and absorption of each piece of glass, it might be reflected again and again in that plane, just in the same manner as the two pencils, or *fasciculæ*, of ordinary and extraordinary refraction can be separated farther and farther apart by the addition of more rhomboids, with their faces and axes all parallel to each other.

The only difference is, that the polarization, without double refraction, is wholly produced by common reflection from the surfaces of homogeneous bodies, such as water in a perfectly liquid state, or glass which has been so annealed or slowly cooled that it has no crystalline structure; and that the double refraction is produced by the crystalline structure of substances, the extraordinary ray being polarized in cases where the ordinary ray is not.

Further, the plane in which light is polarized without double refraction, is always that of the incident and emergent light, while that which is produced by double refraction is always in the plane of the axes of the crystal, and the deviation is the greatest possible when in the direction at right angles to that.

This difference will easily account for the different appearances of the images produced by the two double refractions, with the axis of the crystals at different angles, and the two reflections with the two pieces of glass in different planes.

At positions 1 and 5 in the figure on page 146, the planes are parallel, and so they are at 1 and 5 in the figure on page 153. At the position 1 in both, the refractions, both the double refractions in the one and the ordinary reflections in the other, are all in the same direction; while in 5 and 5 they are, one the one way and the other the other, but both in the same plane. In the case in which there is double refraction, the one reverses the other, and only one spot of entire light appears, as it is found at 5 in the figure on page 146. In the figure on page 153, there is a double refraction to counteract; and therefore the spot of light is the same both at 1 and 5.

In this figure, the whole of the light is polarized to the plane x x, by the reflection from the first piece of glass; and therefore the spot entirely vanishes at the positions 3 and 7, the plane of which is at right angles to the plane x x. But in the figure on page 153, it is only the extraordinary rays which are polarized to the plane 1 4, and thus, in the positions 3 7, there are two images.

In the figure of page 146 there is a confusion of images at the middle of each quadrant, and those images are all faint; but in the second figure, as there is but one refraction in each plane, there is but one faint image.

The identity of polarization by reflection, and polarization by double refraction, may be further illustrated by substituting a rhomboid of Iceland spar in place of the second piece of glass. If the plane of the principal section of the rhomboid is parallel to that of the reflection of the glass, the ray is not divided into two pencils by double refraction, but if the rhomboid is turned round so that its principal section makes an angle with the plane of the reflection, double refraction appears. The two images are most distinct when the planes are at right angles to each other; and they approach nearer as the parallel is approached both ways. They thus follow the very same law, or exhibit the same appearances, as the images produced by the second crystal, when that is turned round on the first. The reflected ray is therefore polarized in the same

direction as the doubly-refracted one; and all the difference is, that the reflection does not exhibit the peculiar phenomena of double refraction, for the reasons that have been already stated.

If the quantity be sufficient, refraction by transmission through a number of thin plates, if all performed or taking place in the same plane, produces polarization; but the dispersions, absorptions, and colourings of portions of the light become so complicated, that they do not very easily admit of popular illustration.

Different substances have different angles of complete, or as it may be more correctly expressed, *greatest* polarization; and, though this does not follow the law of the sines, like that of common refraction, it follows an analogous law. The angle of greatest polarization, that at which all the reflected light is polarized, is always the complement of that of refraction; and therefore the tangent of the polarizing angle is the same as the index of refraction.

Section LI. Natural Colours.

Those slight and otherwise imperceptible differences in the surfaces of substances, by means of which they act upon light so as to produce all the varieties of colour by which the creation around us is rendered so beautiful, are among the most interesting, but at the same time the most difficult subjects in the whole wide field of science.

Light is so fleet that we cannot retain and examine it, and so little alters its appearance, that we are very frequently unable to tell to what cause a very striking change is owing.

Look at a crystal chandelier in a room,—in one place it blazes like diamonds; in another it is crimson; in a third it is golden orange; in a fourth bright yellow; next green; then blue; then purple; and, lastly, dull and rayless. Shift your position but an inch, and you find it a perfect chameleon; for each point that you can note passes through

all the tints of the rainbow in a moment, and before you have moved a finger-breadth.

Look steadfastly at a single candle, or at a lamp in the streets, and if, in the last case, it be partially obscured by a moist or foggy state of the atmosphere so much the better. At first you see only the spiry flame of the candle, or the trefoil or bat's wing of the gas-lamp. But watch it a short time, and all the varied tints of the rainbow will soon surround the flame, which will sport and flicker in all directions in starry points.

If the air be dry, these beautiful colours are produced by the decomposition of light in the little watery film which gathers on your eyes, to defend them from the direct action of the light. If the atmosphere be humid, the humidity which is floating there aids in their formation; and the points of the stars shoot away to greater distances.

A common fire furnishes you with all the tints, according to the intensity with which it burns; and the very stove and the fire-irons paint rainbows for you. If those parts of the stove which are near the fire have been brightened with black-lead, (in reality carburet of iron, or diamond mixed with about nine per cent. of iron,) rainbows will form all over it, which are varied in their hues, as if a dusky veil were drawn over them; and if you leave a bright iron poker with its end in the fire for a little, the part which has not been blackened will be separated from that which has, by a band of rainbow tints.

Nay, so apt is nature in the development of these colours, that we find them in the scum of mantling pools, in the window-glass of stables, and other places where glass is not often cleaned, but allowed to be corroded by foul air. The salts with which beef is cured, when in considerable quantity, give rainbow hues to the fibres when cut across. Everything, in short, that tends to produce a crystalline structure, or a succession of thin plates, having different refractive powers, is rich in these colours.

Nor is it at all necessary that the process by which they are coloured should be carried on in the light. The depth of the mine, the interior of the rock, or even the beds of the ocean, to which but little light can be supposed to penetrate, are all rich in radiant colours. The colours which glance on the natural tables of so generally dull a substance as common pit-coal, are often intensely brilliant; some specimens being distinguished by the name of *peacock* coal on account of its colours resembling the gorgeous hues on the tail of that bird; and those of some other minerals are still more beautiful. The little crystals which form within the solid crust of a common agate, have their points dipped in intense violet, and are admired as amethysts.

Labrador feldspar, which in some lights is merely one dull gray, shows in other lights the most brilliant colours which can be imagined. The colours of pearl-shells, and they are almost all deep-sea ones, are well-known; and the very insects, and refuse of the productions of the sea, often leave their traces in rainbow hues upon the shore; whilst some of the finest dyes have at times been made from small sea-animals.

To mention the colours with which the earth and the sky, and their inhabitants are adorned, is almost unnecessary. They are noticed by all who have eyes, and who employ them aright. It is not even in those colours for which we have distinguishing names, that the wonder of the matter lies. Walk a mile or two over the fields, and count, if you can, how many shades of green you can distinguish. Watch one spreading tree from the opening of the buds in spring to the falling of the leaves in autumn, and you will be unable to name half the changes which are perfectly palpable to your sight. Nay, if you take but the light of one day, "from gray dawn to dewy eve," be the place or the objects which that one day reveals to you what they may, the varieties of colour will alone suffice to furnish you with ample occupation and enjoyment.

The colours of the wild flowers, and how they change

with the period of the year, the variations of the weather, and the nature of the soil, are also remarkable; and what imparts to them greater interest than the leaves, they appear to depend more immediately upon the direct action of the sunbeams. Our grass-fields are as green in winter as in summer; and if the heat be the same, they are all the greener when the weather is dull and showery, and the sun but rarely breaks through the clouds. But in cold and damp places and seasons, the flowers have little beauty. We may range over miles of a marshy country without ever meeting with a red flower; and in rainy summers, the very roses lose their colours, and the whole garden is comparatively cheerless.

So also the orchard. Fruits which grow in damp situations are inferior both in colour and in flavour; so that the appearance and taste of apples are no bad tests of what the season has been.

And when we come to organized beings, the difference produced by climate is as remarkable as that produced by seasons. In the cold regions the flowers are few, and confined to that portion of the year, during which,—by the beautiful contrivance of the obliquity of the earth's axis to the plane of its orbit, which gives the two hemispheres summer and winter in alternate succession, and bestows for a short space continual day to those places of the earth which otherwise could mature no vegetable and support no animal,—summer is uninterrupted. Even while the flowers do appear, they have comparatively little beauty; and a very large proportion of the plants are of those kinds which cannot be said to flower at all.

In those regions there is hardly anything that can be termed a meadow; for during the long winter, the ground is swathed in a mantle of protecting snow; and in the summer, as the fields have little or no night during which to rest from the action of the sun, they are burnt up.

In the regions of the equator, on the other hand, in all cases where there is sufficient moisture to allay the burning heat, all is continual budding, and blossoming, and

fruiting at the same season. The developments of colour there are most splendid; and it seems as if all the living productions of nature vied with each other in beauty; the plants, the insects, the birds—even the reptiles, and many of the fishes, being equally brilliant and boldly contrasted in their colours. But there would be no end of even the simple enumeration. The colours of nature are beyond the compass of human knowledge, description, or imagination.

Section LII. Natural and Artificial Light.

Varied as all these colours are, and much as they are modified by heat and other influences, they are all obtained out of the simple white light, decomposed as it is by the different refrangibility of the severally coloured rays, in the spectrum or the rainbow.

But beautiful as the results of the decomposition of light are, we do not know that any of them contains, in all the variety of its tints, the entire light of the sun; and as little can we say that the beams of the sun are absolute light. There are many lights produced by the process of rapid and violent burning, which, to our perception, are far more intense than the light of the sun; though on account of the small volumes of matter from which they emanate, the most brilliant are not seen above one millionth part of the sun's distance, and not nearly so far when the sun is shining. The light of the sun can, however, be seen at the vast distance of four hundred times the measure from the earth to the sun, which is about the mean distance that the light of the sun must pass over in going to and returning from Uranus, in order that the planet may be seen by us, in the light from the sun which it reflects.

The light of the sun, independently of the colours which it reveals to us, is not, and cannot be absolutely pure sun-light, or entirely separated from other light. Light is so delicate that some portion of it is dispersed, and some absorbed, even in that part of our atmosphere

which is so fine and rare that a feather would sink in it more rapidly than lead does in water. The reflected colours of various substances on the earth, and the refractions and polarizations which are produced by others, further hinder us from knowing with certainty, how much of that which is visible to us as light, comes directly from the sun, and how much not.

Hence we are not sure that the colours in nature are obtained by the same sort of decomposition as that by which we are enabled to obtain similar tints. But still, the light of the sun must be the chief agent in producing colours, because we do not get them nearly so perfect by any other light.

So familiar are people with this fact, that it is quite common to speak of "candle-light" colours as being different from those of sun-light. The tendency of candle-light is to diminish or lower the tint of colours, so that it requires a practised eye to distinguish yellow from white, green from blue, and some of the reds from brown. Our feelings on these subjects are not, however, always to be implicitly relied on; for if we have been much in the habit of judging of anything by the day-light colour, the habit will make us judge of it by that colour, even when it appears of a very different tint to those who are not so well accustomed to it.

Players and others who seek attraction to their appearance, and dress only by the artificial light of gas and candles, make their appearance in glaring colours, which would be very offensive in day-light, and even among those who are familiar with the daily as well as the candle-light aspect of each other. The vermilion and burnt cork with which a performer daubs his face, in order that he may seem a hero or a buffoon, would render him a fright in the streets or on the public walk; and yet, because he wants them when he is there, those who are familiar with his professional appearance think his natural aspect far more pale and sickly than it really is.

Artificial light does not give us that aërial perspective —that nice judgment of distance, which we obtain by means of the natural light of day. But this arises from the small distance to which it extends in revealing objects, and the small portion of it that is scattered by refractions and reflections, as well as from the imperfection of the colours that it reveals.

Carry a candle into the flower-garden, or the conservatory, and you meet with but a sorry sight. There are none of those pure tints and softly melting shadows which the light of the sun gives you, and which makes objects appear so soft, and round, and beautiful. There are a few hard patches of glaring, yet cold and colourless, light; and all the rest is shadow, deepened and made more harsh by the contrast.

But if the same light is tried upon a landscape, even a very limited one, the effect is still worse; and, unless for a few feet or yards around it, an artificial light is the surest way of rendering everything darker and more indistinct. Lamps in towns, if they be abundant enough and judiciously arranged, render the streets light and comfortable; but they darken, by their contrast, those lanes and alleys which their light does not reach. So, also, the lighting up of the high roads makes the cross roads and lanes, where there are no lamps, much more intolerable, dangerous, and unsafe, than they otherwise would be.

When we consider all these facts, it becomes evident, that though the common light of day which we enjoy is, whether we enjoy it in sunshine or shade, a mixture of many lights, yet it is only through its medium that we can study the nature or enjoy the pleasure of colours.

Section LIII. Lights from Surfaces.

All coloured objects may be considered as reflecting from their surfaces two distinct kinds of light; that is, two separate portions of the light which falls on them, differently affected; those portions being both formed out of the same incident light, of course diminish each other; so that

the less perceptible any one of them is, the other one is always the more. Thus, when both are nearly equal, the sum of the two, or the entire light given out by the substance, is the least possible, while that in which one of them is barely sensible, is the one in which the whole *effect* is the greatest.

The first is that portion of the incident light which does not at all penetrate into the substance, but is reflected, or partly reflected and partly dispersed, by the mere surface. Of course it depends wholly upon that surface, and is not affected by the nature of the substance, except in so far as that regulates the character of the surface.

The portion of light so returned may be considered as returned with only greater or less intensity, but not in any way decomposed or affected by refraction. In this way, white light may be reflected from the surface of black marble, red light from a polished mirror or other piece of silver; and, generally speaking, any colour of light that is reflectible can be returned from any coloured surface whatever.

The quantity of surface-reflected light depends on the smoothness and polish, and these again depend upon the closeness and hardness of the substance. In the case of metals and some other substances, there is a difference between a surface polished by burnishing, and one polished by grinding, even when they reflect the same degree of light. The burnished surface is never perfectly true, and therefore it scatters the light much more than a ground one. For common purposes the burnished article is the more showy, because it reflects in all directions; but when as much light as possible is desired in some particular direction, the ground surface is best.

The natural surface of glass stands much in the same relation to the ground and polished surface, as a burnished one does. It is very difficult, if not impossible, to communicate to glass an artificial surface so fine as its natural one; but that natural one is generally irregular. It may be added, that glass, with the natural surface, is always stronger than glass artificially polished.

The quantity of white light reflected by the mere surface, diminishes as that surface is roughened, though if the roughening destroy the transparency of the substance, more light will be turned back from it than if it were smooth. Thus the surface of snow returns more light than that of solid ice, and the surface of very finely-powdered snow more than that of snow in larger masses; but the light so returned is more dispersed.

Walking toward the low sloping sun-light, over snow that has newly fallen in an intense frost, is not very painful to the eyes on account of the reflected light; but after the sun of several days has melted the surface, and the frosts of the nights have turned it to scales of ice, the reflection is intolerable. When the snow begins to melt, too, the effect on the eyes is very disagreeable, even when there is no sun; but in this case the snow is transparent to a certain depth, and the light is partially decomposed and partially also doubly refracted, as there is a tremulous feeling of double vision; just as there is in looking at a printed sheet which has shifted a little during the pull at the printing-press.

When the surface is very smooth and even, it acts like a mirror; and when viewed obliquely, throws the reflection where the other light is not seen. A picture is often so highly varnished, that it appears more like a mirror than a picture, except in one situation, and that is often the very one in which it cannot be seen to advantage. An irregular shining surface is worse, as in all positions it hides the colour and shows only its own deformity. Indeed, when we must take the surface-reflection and the colour together, the beauty of the latter is always lessened.

A portion of light always penetrates below the surface to a greater or less extent. But very little, probably the thousandth, or the millionth, of the smallest thickness that we can measure suffices. This light undergoes decomposition. Part of it is absorbed or dispersed and part returned; and it is the latter portion which produces colour, or rather reveals or shows colour in substances; or the colour is produced by that property of the sub-

stance, by means of which it decomposes the light, and shows off one colour rather than another.

Generally speaking, the colours of substances are not brightest in that direction in which they reflect light, if that reflection be of undecomposed light, as it must be if it is from the mere surface, in which case the reflected light must follow the general law of equality in the angles of incidence and reflections. We may infer this from the fact that the coloured light is refracted and the white light is not; but the refraction often extends so little into the substance, that we can discover nothing further respecting it than the colour which it produces.

One fact which at first sight seems against this, is the necessity of holding woollen cloths, especially dark blues, and browns, and greens, towards the light, as if a reflection, were taken from them before their colours will come out distinctly. But the fact is, that it is transmitted or refracted light through the partially transparent pile of the wool, that is seen in these cases, and the colour is merely the colour in that position, just as a bit of cut glass is green, yellow, or red, according as the light comes to the eye from it.

Another case of a similar nature, only it is a compound one whilst the former is simple, is that of shot silks, or those that have the warp of one colour, and the woof of another. These have different refractive powers in the threads, partly on account of the different dye stuffs with which they are coated, and partly because the lengths of the warp and woof, and also the twists on them, are in contrary directions. Blue and yellow, so as to bring up the green in the half tint, form perhaps the most beautiful of these shot colours.

Surfaces of silk or other showy materials, which have the threads with the twist all the same way brought to the surface, often have, with no difference of colour, a very strong relief, in consequence of the mass of light reflected by the folds.

In damasked fabrics, a pattern is brought out in a

single colour, by throwing the twist of the threads with each other, or the "twill," as it is called, in contrary directions; and greater relief is often produced by giving some parts the satin lustre, and keeping others flat. This last effect is produced in table linen, by subjecting it to the rolling pressure of a mangle.

Any process, indeed, which makes some parts of a surface reflect more light than others, produces a variety of colours out of one. Of this, the "watering," as it is called, of silks and stuffs is an example. It is done wholly by pressure; and the mode of applying that pressure is often nothing more than mere folding.

Nature exceeds all art, however, in producing rich and varying tints by the alternation of little patches of different colours. The pigeon's neck, the green of the drake's head, and the tints of a variety of other birds will occur to any one. Some of the *coleoptera*, or insects that have hard cases to their wings, such as the green midsummer beetle (*scarabæus solstitialis*) which is plentiful in gardens in the warm season, and also some of the bronze-coloured beetles, are beautiful instances of this. Some of the snakes and lizards have it also in very great perfection; and probably there is not, in the whole assemblage of living creatures, a more gaily attired tribe than the little humming-birds, which sport by myriads in the radiant beams of the tropical sun; making the forest gay with greater brilliance than can be displayed by all the caskets of gems in the world. Such is the power which the Great Author of nature has given to his creatures to appear in all the decomposed, compounded, varied, and constrasted glories of the beams of the sun.

Section LIV. Complemental Colours.

Whenever a substance gives out by refraction any one colour other than the pure white light, whether that colour be one which is found of the same shade in the spectrum, or compounded of two or more of these, the

remainder of the light must always be dispersed or absorbed by that substance. If the substance has little or no reflection of intense light at the mere surface, then the more intense must be the colour which it shows by refraction; because it must be produced by the decomposition of a greater quantity of white light in proportion to its extent.

This is found to be the case, both with substances which refract the light, and with those that may be said to absorb the whole of it. The only colour that wholly absorbs is black, and it does so only when it has not a reflecting surface. Black velvet, of which the pile is fine and close, and not in the least bent in any direction, perhaps absorbs as much of the light which falls directly on it as any surface with which we are familiar; and other velvets are all more intense in their colours than fabrics which have a gloss, even though the materials of both are dyed in the same vat. So in the leaves of trees and the petals of flowers, the velvety or lustreless ones are all finer in their tints than those that shine. The cup of a tulip is one of the most lustrous of flowers; and yet, notwithstanding all the richness of its variety, there is no such tint of colour in a tulip as is to be met with in a dahlia, or some of the lobelias.

In the colours of minerals, too, those which do not shine are always the brightest, except in the peculiar kind of metallic lustre which has been alluded to; and that kind of lustre is never produced along with the intensest red.

The light has also, as might be expected, the greatest action upon those lustreless colours; but this can be better noticed when we come to speak of heat.

It is evident that the more pure and intense any one colour is, the more perfectly must the rest of the colours of light be absorbed or dispersed. How much of them is lost by absorption, and how much by dispersion, it is not very easy to find out in all cases, or in any case; but the probability is that some is always disposed of in both ways.

After any one colour has been separated from the white light by a substance which shows that colour by refraction without transmission, the remainder of the light is the *whole complement* of that colour. The colour so refracted may be any simple tint, or any compound one formed by the mixture of two or more simple ones. The complement will, of course, vary accordingly. Some of these complemental colours are sometimes also called the "accidental" colours of each other, because they seem as if they were purposely suited for each other, inasmuch as both look brighter when in contrast side by side than when they alternate with any other tints.

In this sense red and green are the accidental colours of each other, and so are yellow and blue. Any one may see the effect of this, by laying one slip of bright red on a piece of bright green, and another on a piece of bright blue; for although the two slips of red have been cut from the same uniform piece just the moment before, no one would believe, upon retiring a little, and looking at them in the same light, that they could possibly ever have been of the same colour; the one will appear so much brighter than the other. All the other accidental colours may be found in the same way; and the finding of them is an amusing and not altogether a useless exercise; as the contrasts of those colours, though strong, are not harsh, and therefore it is worth while to know how they are formed.

There is another property of these colours, which is still more curious, and more useful; as it not only enables us to see the beauty of colour in higher perfection than we could otherwise see it, but also shows how to economize our eyes in the use of it. The eye is an organ from which we perhaps derive more pleasure than from any other; and it is the only one which we can use at a distance. The loudest sounds are brought to us only from the distance of a few miles; and even then they tell us nothing about that which produces them, unless we have had former experience. Fragrance is wafted for a few

hundred yards; and taste, and what we call touch, are senses of actual contact, and have no enjoyment at even the distance of a hand-breadth.

The eye, on the contrary when in a position favourable for observing, can at one glance, scan the most ample city or the most extended landscape; while its ken penetrates farther into the depths of space than the imagination itself can follow. The finger can reach upwards some six or seven feet from the ground; the ear can hear the murmur of thunder at the distance of eight or ten miles; but the eye can see far among those stars, compared with the distances of which, two hundred millions of miles is too small to be considered a measurable quantity.

It accords, therefore, with that philosophic truth, of which the Bible is the most beautiful as well as the most accurate and invaluable record, to compare whatever is very precious to "the apple of the eye;" and no exertion by which the exercise of so delightful an organ can be improved, or its decay prevented, ought to be indifferent to a rational being. The blind, who have lost the use of their eyes by accidents, and the careless, who have neglected them, and worn them out by improper management, can tell how precious a faculty that of sight is.

Now, in the case of complemental or accidental colours, that have been mentioned, when the eye is fatigued with the observation of any one colour, the accidental one is that to which it becomes the most sensitive, and which affords it the highest gratification. If the eye is fatigued with red, the relief afforded by green is delightfully soothing; and if we have been the whole day in the flowerless meadows among the green grass, the smallest red flower or red berry is a treat.

So natural is the transition from any one of these colours to the other, and so necessary is it to the healthy and vigorous condition of the eye, that when we have overfatigued our sight by looking at the one, the other comes

to the relief of the wearied eye, even when it has no existence in nature.

Any one may prove this by looking stedfastly for some time at the setting sun. From the dispersion of the more refrangible part of the sun-beams by the humid air at that time, the image of the sun is a yellowish red, the accidental colour of which is a purplish green, which is nearly the complemental part of the entire light. Well, look at the sun in that situation till the eyes are fatigued and begin to dazzle; and then turn to the opposite part of the horizon, and it will appear covered over with disks of purplish green, of about the apparent size of that of the sun.

There is a more agreeable illustration of the same fact, in obtaining a new and far more fresh and beautiful view of a fine landscape, especially of one containing many distances, and therefore much aërial perspective, after the eye has been tired and fatigued by looking at it in the usual manner. The plan is simply to invert the head, so that the eyes are turned completely upside down. But it may not be amiss to tell the reason:—

In a landscape, the colours of the sky and the distance, are the reflected and dispersed tints, that have been thrown back, when the colours of the ground, more especially those near the foreground, and which are seen most in their natural colours, have been refracted out of the entire light of the sun by their several subjects. The foreground and distance of the landscape therefore mutually dispose the eye for being sensible to each other, the more it is fatigued by each.

But the erect position of the head being the usual one, and the rays of light crossing each other in the interior of the eye, before they reach the *retina* or nervous tissue which is understood to be more immediately the organ of vision, it follows that the sensations of the ground colours habitually affect the upper part of the retina, and the distance and sky colours the under part.

Hence, when the head is in an erect position, there is,

in the using of the eyes, a satiety produced to the kind of sensation to which each of those parts of the eye is restricted; and at the same time there is a corresponding sensibility produced in each part to the sensations with which the other part is fatigued. The inversion of the head is, therefore, not merely a relief from pain to both parts of the eyes, it is a positive pleasure.

Even after a landscape has been examined and admired for hours with the head in an erect position, and though the observer be fond of fine prospects (and who is not?) on inverting the head, it displays beauties which were unfelt when it first met his uninverted eyes as a novelty. He feels as if the hand of nature had passed over the scene, and painted it anew. The objects at a moderate distance are remarkably clear, and many which were dim and invisible stand graphically out. At the same time the distances are extended, and the whole is absolutely magical.

But delightful as light and what light reveals are, and difficult as it is to quit them, we must proceed to another subject, and one which, if it will not unveil to us so much gentle beauty, will be more fertile in powerful action.

SECTION LV. GENERAL NOTION OF HEAT.—GRAVITATION.

EVEN in the slightest action that we can observe, or indeed that can in any imaginable manner take place, there is some change of heat; and when action of any kind becomes powerful, the display of heat is equally so. A rain-drop, or a feather falling through the air, alters the state of its heat, though to so small a degree that we cannot measure it; but air may be driven with so much force as to set solid substances on fire; or if one piece of ice be dashed with great violence against another, sparks of fire will be produced by their collision.

In common language we give the name "heat" to our own sensation of warmth, and designate that which we

feel as being its opposite by the name "cold." But in using these words, we do not refer to any constant and invariable standard, but merely to our own feeling, which varies with the temperature of the body, and consequently with the circumstances in which the body happens to be at the time of observation.

Thus, if one person who has been exposed to the air out of doors on a keen frosty night, and another who has been sitting by the fire in a close room, enter the same apartment in which there has been no fire for the day, the one from the cold air will feel that apartment pleasantly warm, while the other from the warm room will feel it disagreeably cold. So also, out of doors, a person who is walking briskly, or otherwise actively employed, will feel a glow of heat under the very same temperature of the air that makes a loiterer shiver with cold.

Nay, even different parts of the body will, at the very same time, give the sensations of heat and of cold from the very same substance. The experiment of the three basins of water is often given in illustration of this fact; and as it is as equally satisfactory as it is easily performed, we may repeat the account of it. Take three basins, fill the first with water as hot as the hand can bear, the second with water of nearly the same temperature as the body, and the third with water as cold as can be obtained. Having done so, plunge one hand into the first and the other into the third basin, and let them remain for several minutes; then plunge both at the same instant, and as speedily as possible, into the second basin, which has water at the mean temperature, and the one from the warm water will feel chilling cold, and that from the cold water glowing hot. Many other experiments could be made, all tending to show that our feelings of heat and cold, in external things, are merely relative with regard to the heat of our own bodies.

And of the heat of the body itself, we have not any more certain standard; for that is affected by action both external and internal. If we exert ourselves in any bodily abour, we become warm in the whole body, or the part

exerted, according to circumstances; and if, from any diseased action, any of the natural motions (such as that of the circulation of the blood) which go on without any knowledge or wish on our part, be interrupted, we immediately feel a sense of heat. This heat is not a mere sensation on our part, but an actual increase of temperature, which may be felt by another person, or indicated by the common *thermometer*, or "heat measure."

We can no more tell the original source of heat than we can that of any other natural appearance; and our senses probably inform us less about its nature than they do about the nature of light. Heat, according to the ordinary and popular application of that term, enters more generally and intimately into the constitution of all bodies than light does, and into that of the human body as well as others; and, therefore, when we attempt to form any judgment respecting heat, unaided by suitable instruments, the heat which is in us always confuses and perplexes us.

Heat, like light, cannot be weighed in a scale, or measured by a line, nor can we in any way judge of it but through the medium of some substance which can be weighed and measured; and the weight, which is the absolute measure of quantity in matter, gives no estimate whatever of the degree of heat. A pound of iron (for instance) weighs the same when cold as ice as when it is red hot; and though different degrees of heat alter the bulk of substances, yet the law of the alteration is very different in different substances, and also in the same substances, at different temperatures.

We have, therefore, no means of connecting heat with the general properties of matter; and thus, though we are in the habit of speaking of it as if it were a substance or portion of matter, we do not know it as a substance, or even as a constant or permanent quality of any substance. All that we can know of it is by its appearances, and the effects which are produced upon substances when it appears, or disappears, or when the degree (or as we inaccurately call it, the quantity) of it is increased or dimi-

nished; and those effects are so very different in different substances, that we are unable to lay down any principles in the science of heat, except such as are very general and vague, or such as apply to some particular substances and not to others.

The most general effect of heat is that of counteracting attraction, or the principle by which bodies and the parts of bodies are held together; and thus, before we can be in a condition for even entering upon the study of heat, we must understand what is meant by attraction.

The general meaning of the word *attraction* is, "drawing together," or towards each other; but it is necessary to understand the word in three senses:—

First, as far as observation has gone—and the more that has been observed, the more the doctrine has been proved—every portion of matter has a tendency or attraction toward every other portion, and would obey that tendency as the law of its nature, if not prevented by some opposing cause. A stone falls to the ground when the hand which lifted it up quits it without throwing it. A wall tumbles to the ground when its foundation is undermined or taken away. The clouds distil to the earth in rain when that power of the air which supported them as invisible vapour, or as floating clouds, ceases to act. The water of the streams flows onwards to the sea. The surface of the sea takes the curved form of a globe; and when the influence of the winds that furrowed its surface has ceased, it puts on the smooth glassy expanse which is seen in calms. The dust rolls down the mountain slopes; and the loosened fragments fall from the precipices. All these effects take place without any agency of other substances, and without regard to the particular qualities of the kinds of matter.

So also a cannon bullet, or any other projectile, be it thrown with what force it may, falls to the ground without any new impulse from without, the moment the force with which it was projected is spent. The moon revolves round the earth, the earth and the other planets round

the sun, and the moons of several of those planets around the planets, at rates of motion just sufficient to balance the *weight* with which they would, as pieces of matter, fall to the centres round which they revolve. Even we ourselves tumble to the earth, not only without any effort on our part, but sometimes in spite of all our care; but we never rise again, or move in any direction save that toward the earth, without an effort.

There is not one exception to this tendency but which may be shown to be an effect of the very tendency itself; for when cork swims in water, or smoke rises up in the air, it can always be shown that the one is supported, and the other pushed upwards by a force which is more than equal to its own weight, just in the same manner as one scale of a balance mounts up when there is a greater weight in the other scale.

Hence, it is impossible to resist the conclusion, that there is in matter as such, and without regard to form, or to any of those qualities by which we distinguish one kind of matter from another, a tendency to fall towards other matter, or to be heavy, (*gravis*) or gravitate, when we attempt to move it in the contrary direction. This is called "the law," of *universal gravitation*, or the *general attraction* of matter for matter—the *attraction of gravitation*.

As observed, the laws of this attraction are as simple as they are universal. The *force*, or weight, is directly as the quantity of matter (it is in fact, the measure of that quantity) and inversely as the square of the distance, reckoning from the centre of one piece of matter to the centre of the other. Thus, if three bodies, each containing the same quantity of matter, were placed in a straight line at equal distances from each other, the attractions between the middle one and each of those at the sides would be equal; but the attraction between the two at the sides would be only one-fourth of that between each of them and the middle one.

If two pieces of matter were free to obey this law and

meet, they would meet equally,—that is, the product of the quantity of matter by the distance which each moved would be the same for both. Thus if one weighed a hundred pounds, and the other one pound, and if they were a hundred and one feet asunder, the hundred pound one would move one foot, and the one pound one a hundred feet. They would also move in the same time, or meet at the same instant, and, therefore, the one pound would move a hundred times as fast as the hundred pounds. The point where two bodies thus situated would meet is called the common *centre of gravity*, just as the point at which all the matter in one body would meet, if not affected by the resistance of the other parts, is called the centre of gravity of that one body.

Any larger body thus holds, by the very constitution of matter, a sort of controul over small bodies. Thus, the earth, which is about 8000 miles in diameter, and altogether about four and a half times the weight of the same bulk of water, exerts so powerful an attraction upon all pieces of matter that we can detach, or see detached from its surface, that the largest of them produces no more effect upon its stability than the lightest dew-drop does on the stability of a mountain. If a mass of stone, one hundred feet in diameter, and as heavy, bulk for bulk, as the earth, were projected by a volcano to the height of a mile, it would not disturb the earth to the 250,000 millionth part of an inch, a measure so small that, instead of knowing it, we cannot even imagine it.

Heat can suspend this attraction of gravitation, but not destroy it; for when the heating cause ceases, the force of gravitation is the same as before.

Section LVI. Aggregation and Affinity.

There remain two more species of attraction to be understood before a clear and satisfactory notion can be formed of the action of heat; first, the attraction of aggregation; and secondly, the attraction of affinity.

The *attraction of aggregation*, that is, the chemical aggregation of *adhesion*, and not the mere mechanical joining, is the force with which the parts of bodies, considered as wholes, and without any regard to their being simple or compound, are held together. It is varied in different substances, both in form and intensity, and its variations constitute some of their leading characters.

But it is not a principle of which it is always easy or even possible to see the mode of working, as it sometimes acts in opposition to gravitation, and sometimes in concert with it. Thus, in the formation of a crystal, the attraction of aggregation appears to act independently of gravity; and so it does in the growth of plants and animals; but there are very many cases in which it co-operates with gravity,—as in the stability of mountains, the consistency given to substances by pressure, and many other instances.

The consistency, or, as we call it, the strength of individual substances or pieces of matter depends in a great measure on their aggregation; and thus gives rise to all the distinctions of hardness, stiffness, toughness, and all other tendencies which substances have to resist what would divide them into parts, or alter their shape.

One general distinction between it and gravitation is, that the gravitation appears to be in the particles of matter, independently of each other, and not in the mass; for a stone pounded to dust weighs just the same as when in one entire piece; so that the aggregation is between particle and particle of the individual portion of matter, and between those particles only which are the nearest to each other. Gravitation appears to be common to all matter wherever it happens to be situated, though between very small pieces at very remote distances it is too weak for us to notice it. Aggregation on the other hand operates at only very short distances, and beyond these, the parts of the substance have no more relation to each other than if they had never been united; but yield to the force of gravitation. Thus, when the pitcher is broken, the pieces fall toward the ground, and do not move in the least towards

each other; the dust of a crystal, even of a diamond, of which, while it lasts, the aggregation is perhaps stronger than that of most substances, is as completely separate in powder as if the parts had never been united; and steel itself, when its aggregation is overcome by heat, can be made to flow along the earth like water,—or may even be so scattered that it will yield to the gravitation of the common air, and ascend in vapour.

That species of attraction to which the name of *affinity* is given, differs from aggregation; and is even more complex in its nature, and varied in its action. The attraction of affinity differs from mere mechanical mixture, just as aggregation or cohesion does from mechanical union. Aggregation is understood to hold together only parts that are alike; affinity parts that are different; but the union is so intimate that the difference is not seen, and the substance appears, to those who have not seen the parts separate, as one, or simple.

Common salt is an instance of this kind of attraction, or of the union resulting from it. To a person who is not acquainted with its composition, the salt seems one substance,—at least each of the little crystals of which it is composed seem one and simple. But it can be resolved into two substances, both very unlike salt; or it can be formed by uniting them. These substances are *hydrochloric acid* and *soda*, both of which, when pure, are of a very caustic nature, that is very destructive of the substance of the human body, so that a small part of either taken singly, as compared to what is taken daily in the compound, would produce instant death.

Not only is the salt compounded of these two substances, but each of them also is a compound. Hydrochloric acid, as its name imports, is a compound of *chlorine* with *hydrogen*—one of the elements of water; and it is not a little remarkable, that though chlorine mixes with water, it does not separate the hydrogen of the water, so as to become hydrochloric acid, unless it be acted upon by heat or light. Soda is a compound of *sodium*, a metal, and of

oxygen; so that common salt is a compound of two other compounds.

The union of substances which is the result of this affinity, is not palpable to common observation, but must be found out by experiment, or by carefully watching the action of substances upon each other. For this reason it is called *chemical* union, or chemical combination, which means "secret" combination, and the attraction of which we are speaking is called chemical affinity, or, more correctly, chemical attraction.

Before this species of combination can be formed, the aggregation of each of the component parts of the compound—that which makes it the particular substance it is, and not another, must be destroyed, or at least suspended. There is, indeed, no destruction of attraction of any kind; for, let a substance be compounded ever so often, it may be recovered out of them all, with the very same aggregation, and the very same properties that it had, before it entered into any of them.

We might easily see, that when a chemical combination takes place, the qualities of the compound must be different from those of any of the separate ingredients,—that the substance must be, to common observation, and in as far as its properties are concerned, a new substance. As the number of substances is very great, and the combinations into which they may be formed almost endless, chemistry, or the science of these combinations, is one of the most extensive as well as the most useful of sciences; and though there be comparatively few who know it intimately, and very many who barely know it even by name, there is no one living, even in the rudest state of society, who has not occasion to use it. A meal of victuals cannot be cooked, or even a fire kindled, but upon chemical principles; for unless the experiment had been made, nobody could know that raw food would become mellow by being roasted or boiled, or that fire could be kindled by striking one stone, or rubbing one piece of wood, against another.

Section LVII. Distinction between Mechanical and Chemical.

Unless the difference between mechanical mixture and chemical union be clearly understood, it is impossible to have correct scientific knowledge, or indeed any knowledge deserving the name of science. For, unimportant as this distinction may seem to those who do not understand it, and simple as it is to those who do, it is one of the chief causes of ignorance, and principal sources of error.

The word mechanics is the genitive case plural of the Greek word Μηχανη, (*mēchanē*,) "tool," or "instrument;" and it of course means anything "of, or relating to, or produced by, tools, or instruments." When we say *machine* we use the Greek word itself, with not a great deal of difference in the pronunciation. By a machine we mean a compound tool. The tool is *one* thing between the hand or other power that acts and the thing acted on, as a spade or a saw. In the machine there are *two* or *more* tools that act upon each other; the power acting on the first, that on the second, and so on through the series, till the last produces the effect. Thus, if falling water, a steam-engine, a horse, or anything else turns a wheel, that wheel a shaft, and that shaft moves a saw upwards and downwards, and also brings a log of timber in contact with it, the whole combination is a machine, and the specific name of it is a saw-mill.

Strictly speaking the term machine refers to the art and invention displayed, rather than the nature or strength of the material used in its construction. It is very nearly synonymous with the modern term engine, which, however, is more frequently applied to machines of considerable magnitude, or which require great skill and accuracy in their contrivance. Hence we are accustomed to speak, and with perfect propriety, of a steam-engine and a fire-engine; a copying-machine and an electrical-machine.

Considered in itself, there is no mechanical action in

matter. The only law of matter which is purely mechanical is its uniformity in the fact of gravitation; and, as that is its primary law, it always acts in strict obedience to it, unless when prevented. Bodies never unite or separate, either in the same substance, or in different substances, mechanically. Their mechanical unions or separations are brought about by an instrument; and that instrument is another piece of matter, which must have the *power* of *acting* communicated to it by something that we call an *active force.*

The mill does not turn round without the falling water; the watch does not go, unless the spring is bent up in winding; the spade does not dig without the labourer; and so on, in all mechanical operations, there is always an instrument, and also an operator.

In chemical action, whether the result of that action be union or separation, and whether it take place between the parts of the same substance, or those of different substances, the active force is always in the substance or substances. It is true, that when we bring about chemical action artificially (and very much of the labour of our lives consists in doing that) we employ implements. But these are not *tools* by which the action is directly performed, they are APPARATUS, which means, "preparings," "makings ready," for the operation or action, and not the performing of it. The apparatus being provided, that is, the "preparations" being completed, we begin to EXPERIMENT, which signifies "to try," or "make trial." A number of trials is called a series of experiments, and the knowledge we gain by such trials we denominate *experience.* Thus, if we made trial of the contents of a raw egg, which are soft, and a piece of common glue, which is hard, in the same kettle of boiling water, for a sufficient length of time, we should, if we had no previous knowledge of them, very naturally suppose, that if any change were produced, it would be the same in both. But when we "try," or "make the experiment," we find that the contents of the egg *boil hard,* and the glue *boils soft.* The water and the

treatment we have given them are the same with regard to both; and therefore we say, that boiling hard is a principle or property of the egg, and boiling soft of the glue.

If, instead of putting them in water, we put them in the open fire, we should find that, up to a certain degree of heat, the egg would harden, and the glue soften; but that with greater heat they would both begin to bubble, and give out the smell of *ammonia*, or hartshorn (which is given out by all animal matter when burning), and then inflame, leaving a portion of black ashes, which also would burn away but without flame, till the whole disappeared. We say, therefore, that the two substances have the opposite properties of hardening and softening only up to a certain temperature, and that they subsequently have properties that are nearly similar—namely, those of changing to invisible vapours.

A piece of rock-salt, and one of coarse quartz crystal, are not very unlike each other in external appearance; but if we put them in boiling water, the salt is dissolved, and the crystal remains unaltered.

These are familiar instances of different chemical actions in different substances; and the number of others that have been found by trials is very great. When the trial is one that has not been made before, the result is *new* to us, but it is not an *invention* of something in *itself new;* it is only a *discovery* of something that existed before; but we did not previously know the kind of *apparatus* or preparation necessary for its appearance.

All chemical unions and separations are produced in a similar manner; and, as we shall see more at length afterwards, heat is the grand instrument in them all. But heat is not a mechanical instrument, for it has no gravitation, and gravitation has no effect on it, or it on gravitation, except through other substances, which are the *instruments;* and, therefore, none of the phenomena or appearances which are produced by heat can be in their origin and nature mechanical, whatever may be the mechanical effects upon substances that are obedient to the law of gravitation.

Section LVIII. Modifications of Attraction by Heat.

In the operations of nature, there is no store of prepared materials, out of which things are made, as the carpenter has a store of timber, the blacksmith of iron, and the shoemaker of leather. Indeed, when all the arts are taken into consideration, there is no store of materials for them. The first and most important of all the arts is the finding of the materials; and though, for those things with the growth and production of which we are not acquainted, we must take the stores which already exist in nature, and when these are exhausted, wait for the natural production of more; yet a very large number of the human race, taking them in any country where there are arts, and more especially taking them in all countries, are engaged in furthering the growth and improving the quality of materials; and it is needless to add, that if these were to stay their hands, even for a very short time, the labour of the rest, and the comfort of the whole, would be at an end.

Now, as in these productive parts of human employment, man must be guided by the operations of nature, and as, even when he comes to work them up as prepared materials, he must still be regulated by their natural properties, there is no possibility of proceeding, unless by attending to what promotes those natural operations which we wish to promote, and produces those natural properties which we wish to produce; as well as to what hinders those operations which we wish to hinder, and alters those qualities which we wish to change. Besides these, and the best instruments and means by which they can be accomplished, and how we shall make ourselves most useful and be most happy in the prosecution of them, there is no knowledge of the material creation. Whether we have or have not literally to labour for our daily bread, we must labour in some way, or disappoint the

purposes of our benevolent Creator. It behoves us, therefore, to be well acquainted with these things.

Now, we have not power over matter generally, 'as the potter has over the clay," and we shall show by and by that the potter's power is not one which can be obtained without some exertion in making the requisite conquest. Almost everything that we can use depends at some stage of its preparation, upon causes which we do not understand, or over which we have little or no control; and, therefore, we should carefully inform ourselves respecting the few general principles, the operation of which lies most within the scope of our understanding.

The attractions of aggregation and composition are the grand instruments with which nature works; and all the changes which we see in nature, or can produce in art, are so many compositions and decompositions. But we do not see the beginning; for the longer and the more attentively we study, the more forcibly will the conviction be produced in our minds, that "there can have been but one beginning—a beginning of all things; and that beginning from God."

So true are the words of Solomon, "there is nothing new under the sun," that we find everything made out of something that existed before. The animals, the plants, the land, the waters, nay, the very times and seasons, inherit of their fathers; and before the new can make its appearance, something old must be changed or fall into decay.

The stability of all things, considered merely as matter and without any regard to different kinds of matter, depends on the law of universal gravitation; and when substances have all so far obeyed that law, that each is in its proper place of gravitation, and all in a state of rest, then, except for the operation of other causes, which could suspend that gravitation, and allow other powers to act, the whole would be fixed in death.

So, also, in the case of aggregation, when the individual substances had assumed their respective forms, if there

were no action from without, those forms would continue ever the same; and so, likewise, when affinity had produced its compounds, each according to the full extent of its law, among those compounds there could be no change, unless that change were brought about by something different from them all.

These are all, so to speak, matters which tend to their level, just as, in consequence of one of them (gravitation), the brooks, streams, and rivers tend towards the sea; and as, if there were nothing to call the water back again, the land would speedily become parched and barren, even so would nature soon become dead and silent, if there were nothing to counteract these attractions.

But the earth has its daily motion round its central line, and its annual motion round the sun, without any reference to terrestrial gravitation, or the aggregation or combination of terrestrial substances, though still in such a manner as to leave them at freedom to act. The sunbeams also play upon it, the night covers it with darkness, the moon performs its revolutions, and agitates the ocean with its tides; the light of day waxes and wanes; the heat increases and diminishes; and the seasons come round with their changes—ever varying, yet in their cycles the same. All these come in their due order, and at their appointed times. The consequence is, that no two successive moments are the same; and those very laws or phenomena of matter, which, left to themselves, would bring death over the whole by the uniformity of their action, are made to turn that very uniformity into the means of life, by the instrumentality of those agencies which we cannot obtain in a separate state, and therefore cannot define or explain as matter.

Section LIX. Heat counteracts Attraction.

Of these agencies, heat is the chief—although it is the one anterior to which we cannot carry our observation of material changes.

The general tendency of heat is to counteract gravitation and to lessen cohesion and aggregation; and it does so even in those cases in which, to common observation, it appears to have quite the opposite effect; for even in those cases, in which substances are hardened by heat, we always find that the hardening is owing to the removal of some substance which kept the mass soft, or the loosening of some aggregation or aggregations which prevented a greater degree of solidification from taking place.

Thus, sugar, which is obtained in the state of a liquid juice by bruising the sugar-canes between rollers in a mill, is brought by repeated boilings to the different states of brown sugar, white or refined sugar, and sugar-candy; and unless these boilings are skilfully performed, the sugar remains in the state of soft syrup. But the sugar, as it comes from the cane, is a mechanical mixture of many ingredients, such as water, mucilage, gum and acid; and the mixture of these keeps the little particles of sugar apart from each other, and prevents the action of the cohesive force which would form them into cubical crystals. In the course of the boilings, some of these substances are separated by means of lime, others by ox-blood, whites of eggs, or any other substances which get firm in boiling by giving out to the water in which they are boiled—that water which kept them soft.

The impurities in the cane-juice when separated from the sugary and watery particles which they contained, are, for the most part, lighter than the mixture of sugar and water, and so they rise to the surface, and are removed as scum, while the lime and some others fall to the bottom as dregs.

The quantity of boiling water which is necessary for procuring the separation of these foreign ingredients, is still sufficient to keep the sugar in a state of syrup; and if it were dried off slowly, from the strong attraction that there is between sugar and water (as may be judged of by the readiness with which hard sugar melts in water,) the aggregation of the sugar would never act so powerfully as to form crystals.

In order that it may do so, the mixture is kept boiling, by which means the water passes off in vapour; and the sugar being specifically heavier than water, and not convertible into vapour, except at a much greater heat than water exposed to the air can acquire, remains behind.

When a sufficient quantity of the water has been evaporated, or, as the workmen say, when the syrup has been boiled down "to the proper consistency," a point, the proper determining of which requires experience, the sugar is still dissolved in the remaining water. It is then removed into coolers, and as it cools, it forms into crystals.

Liquid brine is boiled down into salt, and many other operations in the arts are performed upon principles exactly similar; but in all cases where, by the action of heat, whether with the assistance of water or without it, a harder substance than the one operated upon is obtained, the real effect of the heat is the producing of a decomposition, a loosening of some previous union, which hindered the action of that cause to which the formation of the hard substance is owing.

Upon the same principle, the *farina*, or meal of vegetables, whether it be taken from the seeds as in corn, from the roots as in the potato, or from any other part, may be boiled or roasted hard, and so may those animal substances which are called albuminous, such as the white of an egg. Varnishes and japans too, which are mixtures of oil or spirits, with various gums and resins, and sometimes preparations of metals, are made very hard by the application of heat; but still that heat merely evaporates, or dries up, the substance in which they were previously dissolved, in order to render them fit for use. All hardenings of soft substances may therefore be considered as really decompositions; and if the heat were powerful enough, and continued for a sufficient length of time, there is no doubt that every new substance or modification of substance would be in its turn dissolved. Thus, the sugar, or the farina, or the albumen, may all be dissolved into different

kinds of gas, out of which it would be impossible to recompose them by any known process of art.

It deserves always to be borne in mind, that when any substance is organic, and the product of growth either animal or vegetable, there is no way of obtaining it but through the medium of that growth. Though we can promote the growth by artificial means, and thereby get more of the substance, as we obtain flour by the cultivation of wheat, yet we cannot bring that about at our pleasure, independently of the progress of natural events. We can smelt iron out of the ore, or burn the earth into bricks, but we cannot obtain even the smallest possible particle of wheat by any artificial process unassisted by nature.

Section LX. The Solvent Power of Heat.

The general principle of the solvent power of heat is so very important in obtaining a right understanding of the science both of nature and of art, in all their operations and in all their results, that some further simple illustrations of it may not be improper.

The first we shall notice is brick-making. In countries where stone is not to be found at all, or not of a quality suited for the construction of buildings, as is the case in the chalk, clay, and gravel districts of England, the making of bricks is one of the most useful of arts.

It very often happens, that those countries and districts which do not furnish building-stone, excepting at a depth below the surface which renders the obtaining of it impossible at any ordinary expense, are the best adapted for sustaining a crowded population. They are the rich plains, and the lower valleys of navigable rivers, so that their climate is warmer, their productions more valuable, and intercourse between the different parts of them, and also with other countries, can be carried on much more expeditiously and cheaply than in the hilly parts, where the rock is nearer the surface. In the London district, for instance, the clay and gravel

extend three hundred feet below the surface, and much more in some places. Under that there is sand, so that it is not easy to tell at what depth the solid rock may lie. Indeed, the inquiry would be an idle one; because, though it were the finest stone in the world, it would not pay for raising. To bore a little hole through the clay, so as to get at the fine water which is in the sand, and which comes filtering and purifying through that sand all the way from the chalk hills to the north and the south sides of the valley, is a costly operation. Yet in that operation no expense is needed to raise the water to the surface; for the clay above is so much heavier than water, that the pressure of it upon the sand in which the water is, makes the water rise above the surface in a jet, as soon as the opening is made.

In rude states of society, the inhabitants of such places form their habitations of twigs and mud; and when they become a little more civilized, they form them of straw kneaded with clay, or of timber. The common dwellings of the ancient Egyptians appear to have been formed of the first of these materials, for one of the hardships of which the Israelites complained during their bondage in Egypt was, that they were compelled to make "bricks without straw."

In very dry countries, houses may be formed of mud, or of bricks dried in the sun; but these are not suited to the moist climate of England, and the soil is wanted for the purposes of agriculture. Wood for houses is not consistent with extensive cultivation; and such houses are dangerous in towns, because they are so easily set on fire, and a fire once kindled is difficult to quench. We often hear dreadful accounts of the destruction of entire villages and towns of wooden houses, in those parts of America where wood is the chief building-material.

Thus, bricks so prepared as to stand the weather and be cleanly, are the best materials in the places under consideration; and any one who considers the multitude of

people that inhabit the banks even of the Thames, must see that this manufacture must be a very extensive and important one.

Common bricks are first made in the form of a stiff paste; and the ingredients are clay, sand, a little lime, some small coal or ashes, and a trace of iron, from which none of the brick-earths are entirely free. These are mixed and tempered with water to the proper consistency, and then dried in the air; but while they are drying they must be protected from the rain, as that would wholly or partially dissolve them. When dried to the proper consistency they are burned; and the proper degree of burning is that which makes them as hard as possible, without melting them into lumps.

But the process of brick-burning is still a decomposition effected by heat, or rather it is a number of decompositions, some of which facilitate new combinations. The first part of the process, before the brick-kiln gets very hot, is the evaporation of the remaining water, which rises from the kiln in dense white vapour. The lime and the coal or ashes are both burned, the latter carrying a sort of combustion through the entire substance of each brick. The lime gives out carbonic acid, and the combustion of the coal or ashes forms the same compound with the oxygen of the atmosphere. It is this carbonic acid which communicates so deleterious a quality to the invisible fumes of a brick-kiln. The lime and the sand (*silica*, or flint) act upon each other so as partially to form a sort of coarse glass, and the formation of this is further facilitated by a quantity of potash or soda which exists in several of the other materials. This coarse glass is formed, in consequence of the heat loosening the cohesion of some of the ingredients, and then allowing them to unite in other proportions.

The clay (*alumina*) which is always in smaller quantity than the flint (*silica*) does not melt; but the particles of it are cemented together by the glass which is formed of

the silica and the other materials which perform the part of fluxes. Considerable hardness and strength are thus given to the whole.

Section LXI. Pottery.

If we except the art of cooking, which we may suppose to be almost coeval with the discovery of fire, pottery is perhaps the most ancient art which mankind practised. It is true, that, in some countries, the plate is still a leaf, and the cup a shell or the hard covering of a fruit; but whether we read the history of, or examine the world itself, we always find traces of pottery; and the principles of the art show themselves in every clayey place. From the readiness with which clay imbibes water, clay soils form a soft paste in wet weather; and then, when the dry weather arrives and continues for some time, the foot-prints become so many cups, hard in proportion to the intensity and length of the dry season to which they have been exposed.

There is a further discovery in the pottery of nature, namely, that clay alone will not make good vessels. The pure clays when dry always shrink and crack; and deep soils of strong clay open in chasms of considerable width and depth; but they retain their shape without any splitting when there is a proper admixture of sand. Thus, when that admixture is properly attended to, bricks, or vessels of pottery, can be baked in the hot sun of the tropical countries to such a degree of consistency that they will resist, for a considerable time, the solvent power of water. No natural heat of the sun can, however, convert any of the ingredients of the brick into glass; and so, no formation of a mixture of clay can be so indurated by the heat of the sun as not to imbibe moisture.

Brick-burning must have been known at the time when the tower of Babel was built; and pottery must have been familiar to the Egyptians in the days of Moses. That lawgiver is generally believed to have written the Book of Job; and that patriarch, when in his affliction he sat

down among the ashes, "took a *potsherd* (a broken piece of pottery) to scrape himself withal." There is, indeed, reason to believe that the Egyptians were, at a very early period of their history, acquainted with the manufacture of the finer kinds of pottery known by the name of porcelain, and also China-ware (so called from the circumstance of its being first introduced into modern Europe from China); for there are little figures found with mummies in the Egyptian tombs, which are of fine pottery, and coloured blue by the oxide of cobalt,—the very same substance that is used in giving a rich blue to pottery in our own times.

In India, where the customs of the people have remained unchanged for many centuries, the potter is one of the public characters in every village. Sepulchral urns of coarse pottery are dug up in all parts of Britain, even where they can hardly be supposed to have been deposited by the Romans; and the remains of pottery are found not only in the central parts of America, where there are other evidences of a partially civilized native population; but in Upper Canada, and some other parts of North America, where they may be said to be the only memorials of human art.

The Romans were well acquainted with the manufacture of bricks, and the common sorts of potters' ware; and though the porcelain, which was known at Rome, appears to have been brought from Asia, yet the kinds of which they did know the manufacture were remarkably well made. This is proved by the high state of preservation in which Roman bricks, Roman vessels, and Roman tessellated pavements are found in all countries where the Roman people had permanent residence. These are seldom in the least decayed; and the colours and patterns of the pavements are not much inferior to those of our painted floor-cloths, which are, in fact, perishable imitations of the Roman floors.

Pottery is thus one of the most ancient and general, and it is at the same time one of the most useful of

the arts; and, except in so far as the moulding of the articles is concerned, it is wholly a chemical art; as it all depends on the effects which heat has upon the materials that are made use of.

Tiles for roofing, and common chimney and garden-pots, are nothing but more carefully prepared bricks. They resemble in colour and composition the funeral urns that are dug up, only these are better burnt than the modern fabrics. If the latter were buried in a moist soil, they would not resist the decomposing effects of water for so many years as the former have resisted them for centuries.

Section LXII. Materials of Pottery—Clay.

The materials used in potters' ware may be divided into three classes,—the materials which form the substance of the ware, those which communicate colour to it, and those which impart to it the glaze—the coating of glass or enamel.

The principal materials are clay and flint, or sometimes magnesian earth, with some alkaline substance which partially converts the flint into glass.

Granite, the hard mottled stone, which is used for street pavements and other purposes where great strength and durability are required, contains nearly all the materials of the best pottery. Granite is a compound of three substances, not chemically combined, but mechanically united. These are, *quartz*, which is flint, but not in a state fit for using in pottery, as it can be obtained more cheaply from common flints; *mica*, which is in scales or plates of silvery lustre, is the least abundant part, and composed chiefly of magnesia; and *feldspar*, which consists of clay and flint, with about twelve per cent. of potash. The feldspar is the most abundant material in granite, and it is the one used in the potteries.

From the clay and the potash which it contains, feldspar imbibes moisture and dissolves in it more readily than any of the other component parts of granite. When

granite is exposed to heat sufficiently powerful, the feldspar melts into a sort of glass, while the mica separates in black scoria, and the quartz remains unaltered; but it is the silex or quartzy portion of the feldspar that melts by the action of the potash. The compact lavas, greenstones, and other rocks, which bear evidence of having been melted by the action of volcanic fires without exposure to the air, are principally composed of feldspar.

In Cornwall, and other granite countries, extensive beds, and even entire hills of decomposed feldspar, are met with, beautifully white, and of great purity. When the granite is first disintegrated by the decomposition of the feldspar, the latter is gradually washed down, and the quartz and mica form sand on the surface, which is in time swept away by the weather.

The great banks of sand which sometimes occur at the mouths of rivers, are, in part at least, formed by these decompositions. The Tay, the North Esk, the Findhorn, and many of the other rivers in Scotland, furnish instances of this; and they have great part of their courses through granite districts. The clay is often left in beds on the meadows or *holms* along the course of the rivers.

When the feldspar alone is left, it decomposes again, the pure clay is washed down to the bottom of the bed, and the silex blown away in fine sand, and what then remains is pure clay, known by the several names of pipe clay, potters' clay, and china clay (the *kaolin* of the Chinese), according to its quality. It is generally understood, however, that the Chinese kaolin contains a portion of magnesia.

When found in a natural state, the clay of these beds is seldom pure, bnt contains sand, particles of iron, and other matters; and so, for the finer clays, the decomposed feldspar is artificially washed out of the quartz, and the water dried off, leaving it in a cake, which is cut into pieces for sale. Even these, however, contain one-fourth of silica or flint.

In the process of washing, whether by nature or by art,

the potash is separated, and, in consequence, the clay does not melt in the furnace; but as it imbibes a great deal of moisture, it shrinks greatly in parting with that in the fire. This shrinking is in part prevented by increasing the quantity of flint; but this renders the ware brittle, as there is too much glass in the body of it. Magnesia resists the action of water nearly as much as clay yields to it; and as they bear the fire equally, the shrinking is lessened by a portion of magnesian earth.

The best form chosen of that earth is not mica, but soap-stone (*steatite*). This stone is usually found in rocks of *Serpentine*, which is a compound of silica, magnesia, lime, carbonic acid, and other matters. The soap-stone contains equal portions of magnesia and silica, with only one part of alumina to twenty-two of each. It feels unctuous to the touch, like a piece of soap, and it froths with water, and hence its name. Some forms of it are spongy, and are called "mountain cork;" others are in flexible threads, and are the *Amianthus* or *Asbestos*, of which the ancients made their incombustible cloth, and the wicks of their perpetual lamps. From the quantity of silica in the soap-stone, a pottery or porcelain may be formed of it and the clay, or even of it alone with an ingredient to fuse the silica; but soap-stone ware is of inferior specific gravity, and tender. Some of the soap-stones contain a much greater quantity of magnesia, and less silica; and these can be used instead of clay.

The *Meerschaum* of the Germans, *Ecume de mer* of the French, *Spuma maris* of the Spaniards—all of which names mean "scum, or froth of the sea," is a mineral nearly allied to soap-stone, and answers the same purpose. This name is given to it because it froths with water, and has detergent qualities. Bowls of tobacco-pipes are made of it; and they have much more the appearance of a natural substance than potters' ware, and are much stronger than pipes of common clay. The composition, generally speaking, contains more than twice as much silica as magnesia. The aluminous and magnesian earths are

swallowed by rude nations to correct the acidity of their ill-prepared food, and sometimes (as it is said) to appease their appetite; but they can afford no further nourishment than is contained in the carbonic acid and water. Yet as these constitute the chief part of the nutritive ingredients in any vegetable (in a wheaten loaf, for instance) they *may* support life; but from the small proportion they bear to the earths, which are not nutritious at all, they must afford but sorry cheer.

Under whatever name the ingredient which has been described is known, and whether the earth in it which resists the action of the flux in the furnace be alumina or magnesia, or a mixture of both, they are all called clays; and the object of them all is the same—that of furnishing a skeleton of fixed matter, diffused in very minute particles through the whole mass, so that when the cementing substance melts, it may be retained, and the articles may come out of the furnace as little altered in shape and size as possible.

Tiles, garden-pots, and other articles of coarse red clay, may be considered as the link between brick-making and the common potters' ware, which is made of inferior materials and burnt in a lower heat; and the hard glazed tiles, generally called "Dutch tiles," may be considered as the very rudest fabric which, because one of the ingredients is fused, comes under, or approaches the denomination of porcelain.

There is not much difference between the words *pottery* and *porcelain*, when used as substantive names. Every one knows the meaning of the word *pot*, and both that and the Irish term *crock*, from which the word *crockery* is probably derived, show that potters' vessels were first used in cooking. *Porcellana* is the Portuguese for a *cup*; naturally enough applied by the Portuguese, who were the first European nation that visited the Chinese, and saw them drinking tea out of cups. The English for *porcelain* is thus "cupper's ware," and the art of making porcelain is "cuppery."

The clays used for common pottery are chiefly those from Dorset and Devon. They may be considered as the remains of feldspar decomposed in the course of time. They all burn white; but the potters give the preference to the blue clays of Dorset. The brown clays are said to imbibe moisture after they have been burnt as biscuit; and not to part with it all, till the glaze is melted, in consequence of which the glaze cracks into little patches.

Pe-tun-tse is the name which the Chinese give to the fusible ingredient of their fine ware. It is quartz rock, calcined to deprive it of its water of crystallization, and then reduced to a very fine powder. The flux mixed with it is called "oil." It is a thin paste of lime and potash, the latter principally obtained from burnt fern.

In Britain, the corresponding ingredient for fine ware is flint. The flints are procured in the chalk districts,—the coast of Sussex being perhaps the place where they are most abundant and easily obtained. They are burnt to drive off the water they contain, by which means they are rendered white and opaque. They crack in pieces when thrown hot into water, and after that they are ground in mills to a very fine powder. These flints contain about ninety-eight per cent. of pure silica.

Flint is so very abundant and easily procured that, unless in the very coarse pottery which resembles bricks, there is little temptation to use any other sand. The carriage, the burning, and the grinding, may be considered as the whole cost; and the last operation is done by machinery.

Section LXIII. Materials of Pottery—Glazes—Colours.

Though in pottery which is coloured, the colours are always applied before the glaze, yet, as the glaze is an essential part of the pottery, and the colours are not, the glaze deserves to be mentioned first.

The *glaze* is some substance which, at a lower degree

of heat than that necessary for baking the ware, melts into a glass, or enamel on its surface. The intention of the glaze is to give gloss and beauty to the work; and also to prevent liquids from soaking into the body of the ware, which otherwise they would do, and soon destroy the more soft and porous kinds.

The qualities of a good glaze are, that it shall run smooth and even, and not crack, either in cooling, after being melted, or in the using of the articles; that it shall be hard enough not to be scratched by dust and sand; and that it shall not be soluble in any liquid that may be used in the vessels.

The old method of glazing coarse ware was by throwing common salt into the hot kilns or furnaces; and that, rising in vapour, and diffusing itself equally through the *seggars*, or cases containing the articles, formed a glass all over their surfaces. This glaze had the advantage of containing no deleterious ingredient in its composition, but it was sometimes coloured, and also uneven.

The glaze now most generally used for the coarser wares is composed of litharge (protoxide of lead) and powdered flints, two and a half parts in weight of the former to one of the latter. Sometimes feldspar is used instead of the flint; and eight parts of that are used with ten of litharge. This forms a harder glaze than the other, and a better one in every respect, only it is not so transparent and glossy. White lead is also sometimes used instead of litharge; but this makes no difference. The whiteness is communicated by carbonic acid; which is driven off at a lower temperature than is required to melt the glaze, so that the active substance is litharge in both cases.

As the oxides and salts of lead are all poisons, the application of these glazes is very pernicious to the health of the workmen; and it is very unsafe to put anything in which there is strong vinegar into a vessel so glazed, because a portion of the lead in the glaze is thereby converted into acetate of lead, commonly, but very improperly, called sugar of lead, which is one of the most poisonous of

all the salts of that substance. The ease with which the lead glaze, or "raw" glaze, can be applied, the low temperature at which it melts, and its gloss, are, however, great temptations to the use of it. These glazes are applied about the consistency of thin cream, by dipping the articles, and then whirling them round to spread the glaze uniformly.

One part of the oxide of tin and lead produced by burning them together, and one of pure silica, and two of carbonate of potash, make a better and a safer glaze—one which comes nearer to the composition of hard glass.

The common porcelain glazes are made from white lead, flint, powdered glass, and soda; and they *might* be made without the lead. The French use powdered flint, old porcelain, and sulphate of lime, in different proportions; the lime and old porcelain partially forming the flux. There is no deleterious ingredient in these glazes.

It must be borne in mind, that the injury done by the glazes which contain lead, falls upon the workmen rather than the users. The proportion of lead must be very great, and the temperature at which it melts very low, before it be decomposed by any but strong acids; and, except in the single instance of acetic acid (vinegar) there is little acid used in cookery.

Glazes quite free from lead, and still more completely fusible than the body of the ware, could be composed of feldspar, flint, and potash; but then these would approach too near to the condition of glass, and would shrink in cooling, and be full of little cracks. That the glaze and the vessel shall undergo the same changes of bulk with the same changes of temperature, is an essential requisite. The glaze of the common French porcelain contains too much of the ingredients of common flint glass, and too little alumina. It has thus a glassy appearance, and gives a milkiness to the colours; and it is in appearance as well as in strength very inferior to the common porcelain of England, and the better sort in France.

The *colours* applied to pottery must, in order that they

may be fixed, and not crack or wear off, be all made of metallic oxides, and put on before the glaze, that being fused over them; or they must be prepared in glass, so as to form an enamel of themselves. The first of these is the cheapest method, and, therefore, it is the one generally adopted. In the finer sorts, these colours are applied by the hand, and some of the best specimens are as highly finished as paintings upon any other substance; but the patterns on the common ware are made by prints from copper-plates, and some of these are very neat and tasteful.

The colours are ground to the proper consistency, either in some of the volatile oils, as oil of turpentine, or in gum-water; and they are mixed with fluxes composed of glass, borax, and nitrate of potash, when ground in oil; and glass, lead, and silica, when ground in gum-water. On the very best, or "hard" porcelains—those which require the strongest heat to fuse the siliceous part—the flux for the colours is composed chiefly of feldspar. If a moderate portion of lime is mixed with the feldspar, it makes it fuse more readily, without affecting the quality of the ware, but too much potash or soda is apt to injure the colours.

The metallic oxides which afford colours fit for applying to pottery, are very numerous; and there are only three precautions necessary in the use of them; first, that they shall not pass into vapour at the heat necessary for fusing them and the flux; secondly, that they shall not be altered in the tint by considerable differences of heat; and thirdly, that they shall harmonize with the flux which is used, so as to melt equally, and not scale or run into spots. All these properties have to be found out by repeated trials; and the composition of the *biscuit* or body of the ware should be tried along with them; for it often happens, that the colour and flux that answer best for one composition and degree of hardness, do not answer so well when these are different.

The colours used in printing on pottery do not essentially differ from those used in painting on it, only as the

printed ware is by much the cheaper, the less expensive colours are used; and there generally is but one colour, though it would be easy to apply a great number. The printed colours are all put on under the glaze, so that it is not necessary to temper them into an enamel with fluxes. They are accordingly ground in boiled oil to the consistence of copper-plate ink, and printed from the copper-plates on soaped paper. This is done in order that the paper may not absorb the colour, as it partially does in common copper-plate printing.

Section LXIV. Preparation of Materials—Kinds of Pottery.

The different parts of the process of pottery are nearly the same in principle for all the kinds, the chief difference being in the proportions of the materials, and the degree of care and labour with which they are worked.

The first operation is preparing the materials—the clay and the flints. The clay is worked, or, as the workmen call it, "bludged," with water in a trough, till the two be thoroughly united, and the mass is like cream. This is then boulted through a succession of sieves, increasing in fineness to the quality desired; and what remains in the sieves is returned to the trough to be bludged anew. The flints are calcined, thrown into water when red hot, and then ground with a little water in the flint-mill. This mill consists of a cylindrical vat, the bottom of which is paved with *hornstone*, and the rolling millstones of the same. This stone is hard and tough; and, as it contains more than ninety-eight per cent. of silica, the particles worn from itself answer almost as well as the flint. Its other solid ingredients are three-fourth per cent. of alumina, and one-fourth per cent. of iron; the first of which can do no harm, the second very little.

The clay and the flints, in paste, are supposed to be in the proper state for mixing into "slip," as the mixture is called, when the clay weighs one pound and a-half a pint

measure, and the flint two pounds. The mixture is next boiled and evaporated in the slip-kiln; but it must be carefully stirred as long as the operation can be performed, otherwise the flint would fall to the bottom and the clay come to the top. But the tendency of the two ingredients to separate is not nearly so great as the difference of their specific gravities; for alumina and silica have an attraction for each other, and when mixed in due proportion, and simply dried, they resist the action of water for a considerable time. This property is taken advantage of in those districts where lime is not easily procured; mortar is made of clay and sand, and used in building with stone, and also for the floors of barns and cottages. Walls are also made of straw mixed with it, and hung across horizontal laths, so that the ends of each row lap over the top of the row under them. These, when properly dried, and protected by a projecting roof, last a very long time, and are close and warm. Probably this was the species of *bricks* which the Israelites made with straw in Egypt.

After the ingredients have been evaporated in the slip-kiln to a tough paste, the paste is worked till it be very perfectly incorporated, uniform, and free from air bubbles. The longer the prepared clay is kept in the state of complete mixture before it is used, the better. This fact holds true even of common brick earth, which is always the better for being mixed one year and moulded into bricks the next.

The proportions of the ingredients vary; but for common pottery, about one-fourth clay and three-fourths flint is nearly the average; and it is difficult to procure the common clays without a little lime and iron. If the ware is to have a fine white colour, there is always a little of the pure China clay mixed with it; but as that is the most costly material used by the potter, he employs it as sparingly as he can.

The "stone-ware," or brown stone-ware, which, though more rough in appearance, is much stronger and more compact than the common ware, is made of clay and flint

only, the clay containing a portion of iron, which gives it the grayish colour shown in the fracture. The proportion is about nine of clay to seven of flint, when they are in the liquid state. This ware is water-tight without glaze; but to prevent absorption the better kinds, as for instance, pickle and preserving jars and the large bottles used for spirits and vinegar, are glazed on the inside with glass in which no metallic oxide or other deleterious material is used.

In porcelain, the quantity of alumina, or of alumina and magnesia, is in greater proportion. If the porcelain is to be of good body, the clay must form at least eight-tenths of the whole; and a portion of the remainder is lime. The lime is usually added in the state of plaster of Paris (or sulphate) but sometimes, the phosphate, obtained by burning bones. This gives a beautiful white; but it makes the ware tender, and liable to break with sudden changes of temperature. If the silica or flux are in much greater proportion than has been stated, the porcelain is too transparent and glassy; and though it stands more heat than common glass, it gets out of shape at high temperatures; and is tender and brittle. Too much transparency, and that texture which appears as if one could "see into it," are always signs of inferior porcelain.

There are coloured porcelains of various kinds formed of basalt and other volcanic rocks, with different ingredients.

Section LXV. Process of Pottery.

Circular vessels are still made, or "thrown," by the potter's wheel, an implement, the construction of which is of the most remote antiquity. The wheel is a small circular board on the top of an upright spindle, to which a rapid revolving motion is communicated by a band passing over a larger wheel. This wheel is turned by a boy, by power from a steam-engine, or by any other force; and the potter sits at the wheel as at a table. When he would

fashion any utensil, a jug for instance, he takes the necessary portion of clay, throws it on the centre of the wheel, puts the fingers of one hand on the middle and the palm of the other on the outside, and pressing both hands together and to a side as may be necessary, he draws up the rude vessel in an instant. Then he rectifies the shape with his hand on the outside and with a wooden tool on the inside, till he is satisfied; after which he cuts it from the wheel with a wire; a boy carries it off to dry, and he proceeds with another. There are also wheels with an elliptical movement for throwing oval vessels; and the number of vessels that a man can throw in a day is astonishing. Vessels of irregular shapes are made in moulds of plaster; and when "clean" moulded, they need no more polish.

When the "thrown" vessels are so much dried that they will bear the operation, they are trimmed and finished on a common lathe; and any parts, such as spouts, handles, feet, or embossed figures, which could not be produced at the wheel, are put on, a little of the moist substance serving for a cement. After the form is completed, the articles are dried in a stove to prepare them for baking.

In order to be baked, the vessels are placed in *seggars* or cases of fire clay, which stand the better if the new clay is mixed with the powder of old ones. The seggars are piled one above the other; but there are never two tiers of vessels in the same seggar. A layer of sand prevents the bottom of the vessels from adhering to the base of the seggar, and the seggars keep the vessels from the unequal action of the direct fire.

These seggars have no tops, the bottom of each in the pile answering for a top to that below. When the kiln or oven is charged, fuel is put in and lighted. The kiln or oven is an air furnace with four draft holes below, and a narrow opening at top. It is heated slowly at first, but the heat is increased to as high a degree as the kind of ware requires; and after it has been found by trial pieces,

placed so that the workman can withdraw them, and the baking has been carried far enough, all the apertures of the oven are closed, so that it may cool as slowly as possible. Some of the makers of inferior and low-priced ware, indeed, withdraw the vessels from the seggars before they are cold, in order to get part of the heat for a new baking; but the exposure to the air "chills" them, and they are very brittle, as the vitrified part resembles unannealed glass.

When the ware has thus been baked, or fired, it is called "biscuit;" in which state the coarse wares imbibe water very readily; and even the porcelains of Europe, excepting some of the "stone" porcelains that are not intended to be glazed, are apt to imbibe a little. The quantity is small, however, compared with that which they imbibe before baking, and that is the reason why they are all converted into biscuit before they are coloured or glazed.

The old method of glazing by salt (which is still used for some of the brown stone) was put on at one baking, but if the raw-glaze were so put on, the moisture of it would get into the body of the unbaked ware, and as that shrinks in the fire, the glaze would be cracked and uneven. Whether it be owing to more skilful management, to the micaceous earth in the kaolin, or to some other cause, the Chinese porcelains have both the colours and the glaze applied before baking, so that unless when more delicate colours have to be added, the ware passes but once through the fire; and thus the Chinese glaze is as hard as the body of the ware, while the European glazes are not.

In colouring printed ware, the papers with the printed patterns are applied neatly, with their printed sides still wet, to its surface; and they are left there for about an hour. During that time the biscuit absorbs the oil; and the articles being put in warm water, the paper peels off. They are then set in a moderate oven to evaporate the oil; after which they are dipped in the glaze, and fired to fuse

it. This glaze always looks glassy and transparent, and wants the solidity of enamel.

The more common kinds of painting are made in the same manner and glazed over; but in the highly-finished ones, some of the colours are put in at the full heat of the furnace, and the second ones, which are formed of enamels, at a low termperature. Thus, in all highly-painted porcelains, the enamel colours are not at all so hard as the general surface, and therefore in time wear out. The colours of the "first firing," such as the Nankin blue of China, are durable as the ware itself.

The manufacture of pottery is so important, and it embraces so much of the science and practical application of heat, that it has been thought advisable to treat it somewhat more at length than has been done with most other subjects. Still, what has been stated are merely detached hints.

There is no portion of human art in which the advantages of science are more clearly seen than in that of pottery, more especially the formation of porcelain, and the glazes and colours. The rude unglazed ware is simple enough, and must, as was hinted, have suggested itself from the observation of nature; but the porcelain and the glaze involve the whole process of glass-making even in far greater variety than it is performed in the glass-houses; and the colours involve the whole science of metals and metallic oxides.

It may also be mentioned, that though porcelain shrinks in the fire, figures moulded in biscuit retain their form and sharpness in a manner which those in glass do not; because the porcelain shrinks equally, while the glass not only shrinks unequally, but falls from the upper part of the mould by its weight.

Many other instances might be given, such as the making of glass, and the smelting of metals out of their ores (the earths, or stones, or other forms in which they are met with in an impure state). But those which have been adduced must suffice; and we may consider it as a

general law to which there is no exception, that when heat acts in any way upon matter, it always exerts a solvent or separating power, either separating different substances from each other, or loosening the cohesion of the parts of one substance.

The changes which are thus effected in the appearances and properties of bodies by heat, are almost without number; and many of them are the very reverse of what we should suppose, if we were to reason about them as we do about common matters.

Thus, if we were to reason by analogy, we should conclude that the attraction of aggregation which produces the hardest substance—the substance most difficult to be cut or broken, would be also the most powerful in other respects, such, for instance, as against the influence of heat, and of other attractions. But this is so far from being the case, that diamond, which is the hardest substance known, does not crystallize when, as in the purest kinds of common charcoal, it contains not more than the fifty-thousandth part of its weight of hydrogen.

Section LXVI. Resemblances between Heat and Light.

Besides the fact that when any substance is sufficiently heated, it gives out light, and the existence of heat as a specific part, or action, of the sun-beams, there are many circumstances which point to the conclusion, that light and heat have a very close connexion.

Heat is radiated, reflected, absorbed, transmitted and dispersed by different substances and in different degrees in the same manner as light; and though, as the two do not address themselves to the same sense, we may have the feeling of the one when we have not that of the other, or though different substances may make the one sensible to our perception or our instruments when there is no sign whatever of the presence of the other, that

is no conclusive argument against both being present even then.

The quality, or rather colour of the light which emanates from different substances during the process of Combustion, and which depends on the nature of the materials of which they are composed, affords no certain criterion of its heating properties. Generally speaking, a pale and blue light, as of sulphur and spirits of wine, for instance, is accompanied by less heat than when the light is white. But there are exceptions to this; the most remarkable example of which is furnished by the combustion of oxygen and hydrogen gases, in the proportions which form water, the light from which is scarcely visible in daylight, whilst its heat is so intense, that the most refractory substances yield to its influence.

When light shows us nothing but the dark colour of a ploughed field, we never imagine that the green rays which would show the growing crop, or the yellow that would indicate the ripe harvest, are wanting; and when we find the rose-tree without a flower, we never blame the sun-beam for the absence of the flower, or once entertain the notion that they have ceased to possess that species of light, which gives us the colour of roses. We at once attribute the absence of any one colour to the absence of that which alone can impress us with the sensation of that colour; and so also when heat is not felt, ought we, if the concomitant light be there, to attribute the absence of perceptible heat to the absence of that cause which could render it perceptible.

It must not be objected, that heat acts powerfully on the structure and state of bodies, decomposing, dissolving, burning, and otherwise changing them; and that light does not. For when we say that heat dissolves, or burns, or produces any other effect, we so far speak figuratively. The heat that we feel is a quality of that which is hot; and combustion is one of the visible signs of a change which is taking place in the fuel, and in the air by which the process is maintained.

One remarkable coincidence between the two is, that making allowances for the different refrangibilities of the colouring and heating rays of light, they are both polarized in precisely the same manner. For, if the heat of the sun-beams be once reflected or refracted at the polarizing angle, it can no more be reflected at the same angle in a plane at right angle to that, than the light can be. It is true, that the angle at which the heat is polarized may be a little different from that which polarizes the light, and we might infer as much from the fact that the heat is at the least refrangible end of the spectrum; but so do the angles, at which the several colours are polarized, differ a little from each other.

Nor does it prove a difference in kind or in origin, that heat acts much more powerfully on bodies than light does. We feel that there are differences in the action of differently coloured light upon our organs of vision, independently of the mere sensation of colour. There is an absolute pain in the continued looking at red, which we do not feel at looking at any of the more refracted colours of the spectrum.

Besides, we know but little about the action of light on substances, though unquestionably it is much greater than we can well understand. This is proved in vegetables, not by their colours merely, but by the actual composition of their substances. Plants that grow in the dark are not only blanched, but they do not make carbon, and many of the other products which are found in plants exposed to the light. Many tropical plants, too, which flower abundantly in their native places, will not flower in our artificial hot-houses, though they have stems and leaves in abundance. We can give them tropical heat in these places, but we are unable to give them tropical sun-beams, and so the circumstances most favourable to them are not complete.

The interior, or heart, of many common vegetables, as endive, lettuce, and cabbage, affords a familiar illustration of the influence of light. If this part be exposed, it is unfit

for food, an effect which seems the result of the chemical rather than that of the luminous, or heating, agencies of the sun-beams.

Nor is the influence of light less apparent in the animal world. The dull and sombre hues of animals which inhabit cold climates may be strikingly contrasted with the rich and gaudy colours of those which bask in the full sunshine of the tropics. To the human species also a due proportion of light, as well as heat, is essential to health, or at any rate to a healthful appearance. We look in vain for the ruddy cheeks of the milk-maid or the plough-boy amidst the densely populated and murky alleys of large towns; and we need hardly mention that miners generally exhibit countenances which are pallid and unhealthy.

Section LXVII. Sensation of Light and Heat.

Our sensation of light is, however, much more delicate than our sensation of heat; and therefore we see the former at distances really greater than we feel the latter; and the effect of heat upon all kinds of matter is also much more limited in distance than that of light.

When the volcanic fire of Etna rages, and the column of flame mounts up over its summit, the light is seen not only through all the island of Sicily, but to great distances over the Mediterranean; and yet the snow lies unmelted within a short distance of the burning crater.

One of the most picturesque, if not the most splendid, displays of light from fires in England, is that of the iron works, on the road between Wolverhampton and Birmingham. During the day, the sky is clouded with smoke, the vegetation blackened with soot, the hollows absolutely overflowing with carbonic acid gas, and the ground formed into hills of cinders and scoria, so that the district has anything but an inviting appearance. But when night sets in—and the darker the better—the appearance is truly grand, and worth a night journey. The perpetual gleams of the furnaces, the alternating ones of the forges, the

lurid glare of the hot scoria, the gloomy reflections from the columns of smoke, the spectre-like appearance of the human beings flitting before and between the fires, now dark, now light, on the one side and again on the other, as they move about, and the dull gloom of the sky, all conspire to form a prospect that can neither be described nor painted. On the surface, light is the prevailing appearance; but notwithstanding all the light and all the actual fire visible, we feel no heat in passing along the road.

It is a curious fact, the reason of which is but very imperfectly understood, that the direct light of the sun soon extinguishes a fire; and not only hides the light of a candle, but reduces the flame almost to nothing. Even light, which is not that of the direct sun-beams, has similar effects, powerful in proportion to its brightness. It is difficult to keep even a tolerable fire in a room which has a large window opposite the chimney. A fire which has burnt dull and languid during daylight, becomes brisk when darkness sets in; and it burns better at night than during the day, notwithstanding the light of lamps or candles.

From what has just been mentioned of the tendency of light in extinguishing fire, let it not be supposed that in the common mode of arrangement there is any tendency in one part of a fire to extinguish another. For the greater the fire is, the more abundantly and rapidly the oxygen comes to it. If, however, the fire covers a large space, and oxygen can come to it only from the sides, there is but a slow combustion, or no combustion at all in the centre. In burning furze or heath on the ground, if a ring of fire is kindled, it makes very little progress inwards, compared with what it makes outwards.

It is the same with any flame that proceeds from the combustion of the ordinary kinds of fuel or of light-giving materials. The flame of a candle may be taken as a familiar instance, which consists of a hollow cone of luminous matter, the interior being occupied by vaporised tallow. At its base, the flame is of a deep blue colour. It

is here that the wick is first heated, and the tallow melted, from which the other parts of the flame receive their supplies. It would take a long time to explain all the phenomena exhibited by a candle. We may state, briefly, that the tallow is first liquefied immediately around the wick, and forming there a small cup or reservoir, it thence gradually ascends among the fibres of the wick, by what is termed capillary attraction, as it is needed. It is next vaporised, and then converted into gas, consisting of hydrogen and carbon, and resembling, in all its essential properties, common coal gas. The combustion of the candle is sustained by the union of the gas proceeding from the vaporised tallow, with oxygen from the atmosphere, which union, taking place *only* at the exterior surface of the flame, will account for its hollow structure. The light-producing agent in this, as in every other ordinary process for procuring artificial light, is carbon (charcoal), which by its union with oxygen at a certain temperature, and under particular circumstances, becomes luminous. If the oxygen be made to combine with the carbon too rapidly, it will not yield light; as may be proved by blowing on the flame of a candle, or lamp, which will thereby be rendered entirely blue. The products resulting from the combustion of a common tallow candle, are water, and carbonic acid—the first being formed by the union of oxygen with hydrogen, and the last by the union of oxygen with carbon.

It need hardly be mentioned, that the process which it has taken several minutes to describe, is the work only of an instant of time. Indeed, it may very properly be said, that the heating, the liquefying, the vaporising, the inflaming, the illuminating, and the decomposing processes, proceed simultaneously; and thus a tallow candle becomes an epitome of all the grand operations by which we obtain heat and light, throughout the entire range of art, manufacture, and commercial enterprise.

Section LXVIII. State of Bodies as depending on Heat.

When we speak of the state of bodies as depending upon heat, we must be careful to put out of consideration their sensible heat as felt by our bodies, or as indicated by our common thermometers, or any other thermometric tests. This has nothing to do with the state of the body, properly so called, though it be one of the qualities, or properties of the body, as felt by us.

The heat upon which the state of bodies depends, is not sensible at all, either to our touch or to our instruments; and therefore it is called latent, that is, "concealed" heat, in order to distinguish it from sensible, or "apparent" heat.

The existence of latent heat is altogether a matter of philosophical discovery; and is, therefore, not known to those who are unacquainted with science. Many people would be astonished if they were told that for the heat of our common fires, by which so many valuable services are performed, we are indebted to the common air of the atmosphere, and that it is produced by the oxygen in it which forms only 21 per cent. in bulk or volume of the whole; and the colder the atmosphere is, the more heat is obtained out of the same bulk of it. Yet these facts are familiar to the merest novice in science. Indeed, though they cannot, of course, explain the principles, the very rudest people upon earth—for there are no human beings so rude as not to know the use of fire—act upon this principle every day.

Why else do they blow the fire? This is merely forcing a current of atmospheric air upon it, the oxygen of which combines with the vaporised carbon of the fuel, and forms carbonic acid gas; and as this gas occupies no more space than the oxygen did, heat is given out during its formation. There are, indeed, other combinations formed when fuel burns with *flame*, in which heat is produced, and

which will be noticed in another section; but they, too, depend equally upon the presence of oxygen.

There is a very simple proof of this within everybody's reach. The same oxygen which supports combustion supports life in breathing; and on this account oxygen is sometimes called "vital air," or the vital part of the atmosphere; and in common breathing, without effort, nearly the whole of the oxygen of the air taken into the lungs is consumed. The volume of breath expired is as great as that inspired, or perhaps a little greater; as all the oxygen that is separated from the nitrogen, or other ingredients, which form seventy-nine per cent. of the common atmosphere, returns again in the state of carbonic acid, and with more sensible heat, so that the expired breath must, besides the vapour of water which it contains, exceed the inspired breath in volume.

Thus, the breath which comes from the lungs, or which is expired when we "blow hot," as it is called, wants the fire-supporting oxygen; and accordingly, if we "blow hot" on the flame of a candle, which we can do only very slowly, the flame lessens, and becomes redder in the colour, just as a fading fire does. On the other hand, if we "blow cold," that is, blow air which has not been affected by the lungs, and do not blow so strongly as to cool the tallow or the wick below the temperature at which they burn, the flame becomes brighter.

Many artists who work in metals avail themselves of this effect of blowing cold; and by means of "blow-pipes," that is, of pipes with a wide end next the mouth, and a narrow opening at the other end, produce a very powerful heat by blowing sideways across the flame of a candle. In this case, however, the oxygen is made to unite so rapidly with the flame that the part acted upon becomes blue. Bellows act upon the same principle; and so do *air-furnaces*, or furnaces which have openings for admitting the air slantingly upwards to them, and *blast-furnaces*, or those into which air is forced by some sort of machinery. The action of these can, however, be more clearly ex-

plained afterwards, when we have brought some more of the principles into consideration.

In all these cases, and in every case that can be mentioned in which heat is attended with combustion, or the act of burning, in any degree which produces sensible light, and even when there is no sensible light, as in the heating of the bodies of animals by breathing or by exercise, or in the rubbing of one substance against another, it is always the latent heat of something that is obtained (out of that thing as it were), and becomes sensible. Generally speaking, the less sensible heat the substance has—more especially if it be in the aëriform state,—the more easily and successfully is the requisite portion (or rather degree) of its latent heat obtained from it.

These facts are so very important toward understanding the general phenomena of heat, and those phenomena are of so much importance, not only in the science of nature, but in the whole business of life, and in life itself and its comfortable enjoyment, that every one should bear them fully and carefully in mind.

Section LXIX. States of Bodies.

It may be worth while to mention that the word *body* is used in a scientific sense, as a general name for every kind, or piece, or portion of matter, that is, of what we can know as matter, by its having gravitation or weight, and occupying space. The particular quantity of weight or of space, though characteristic of the particular body to which it belongs, as distinguishing it from other bodies of different weight or space, has nothing to do with the general meaning of the word. The sun, which is nearly 334,000 times as heavy as the earth which we inhabit, and, in round numbers, about 1,400,000 times as large, is a body; and so is the smallest pin's head or grain of dust —or a portion of air, less than the ten thousandth of any nameable part, of the smallest of them.

But light is not a body, neither is heat; for we cannot

attribute weight to either of them; and as little can we know anything about their existence in space, except by their effect upon something else, which really is a body, and exists in the same space at the same time.

We do sometimes use such expressions as "a body of heat," "a body of light," or, "a volume," meaning a certain bulk of either. But these are figurative expressions—they *express* one thing and *mean* another. Such expressions not unfrequently mislead those who do not see their double meaning, even in common language; and we should be especially careful of using them in the language of science.

When, however, we have found the two parts of any of those relations, so as to be certain that the relation is constant, we can *infer* either of them from the other, but we must be careful not to misplace them in our original scientific view, otherwise we so far close the door upon ourselves. We can infer backwards in thought, but we cannot infer backwards in fact. We can as easily think that we could get the fire from the ashes as the ashes from the fire; but when we come to try, it is quite another matter.

This is the most important caution in all science; and the neglect of it has been the cause of every unintentional error that ever was committed in science—or in anything else.

The general states of bodies, as depending on latent heat, are three; the solid, the liquid, and the aëriform or gaseous. *Solids* always have their distinctive name, but *liquids* and *gases* are often both called *fluids*, and there are various modes of discriminating them as fluids of different forms. But none of these is quite free from objection, so that *liquid* and *gas* are the best scientific names for substances as being in the states of *liquidity* or *gaseality*. The word *gas*, though a German word, is better than the naturalized Latin word *air*, as that is the common name of the atmosphere, which always contains the two gases that have been mentioned, and

generally a trace of others; and the two, the oxygen and nitrogen, are either not chemically combined at all, or very slightly, as they are separated by the very gentlest operations in nature.

We have no reason to doubt that all bodies in nature may exist, under some circumstances, in any one of the three states—solid, liquid, or gaseous. Our actual experimental knowledge is necessarily confined to the circumstances under our control, and these are very limited; but we must not limit the operations of nature to these. These operations are God's working; and, though it be equally our duty, our pleasure, and our profit, to search into them as much as ever we can, not only that we may obtain new and improved modes of action and objects of possession in this world, but also that we may obtain more reverential and delightful perceptions of that Almighty One, the impress of whose Being and Attributes is upon Creation in all its parts, and in all their appearances; yet it would be presumption to imagine that we could know the whole.

A little hint will, however, often enable us to see a great way. An instance will best prove this:—suppose in some distant isle, which our science, and those arts which are its fruits, have not reached, an untutored man to be standing on the sea-beach, looking towards a few little specks in the horizon, and all anxiety to know whether they were the canoes containing the flower of his kinsmen, or a hostile fleet coming, in the absence of these, to burn the villages, kill the old men, and carry the women and children into captivity. Suppose also that the man made known his trouble to you, and implored your aid. What would be his indignation—his outraged feeling and insulted understanding,—if you filled one hand with sea-weed from the rock, and the other with sand from the beach, and went up to him, saying, "Here, take these; mix them, and apply them to your eyes, and you shall see what you wish in a moment!"

Yet this is, in truth, the only advice you could give him; and, if the mixture could be made, and fashioned,

and fitted, in as little time as the words can be said, it would answer the purpose completely. These are the materials of glass, of which the lenses of a telescope are made. But, if you were a scientific and well-provided traveller, you would have your glass in your pocket, and taking it out, you would adjust its focus, lay it across a rock or hillock, so as to bear on the objects, and say to the man, "look there;" and he would instantly be satisfied. Now the discovery that sand and sea-weed melt into glass was but a little hint; and yet it has carried human vision, not only far over the earth, but far into the heavens.

Well, from the hints we have in the substances that have been examined we have reason to believe that solid, and liquid, and gaseous, are three states of all bodies, and dependent on different degrees and modifications of heat; and that the real properties of the bodies are certain qualities in them that dispose them to assume these states, in every case where the degree of heat and all other circumstances are the same.

The degree of the state has nothing to do with the degree of heat, but depends on the disposing qualities of the body, the knowledge of which is matter of observation or experiment, and must be understood to be constant in the same kind of body under the same circumstances, otherwise there would be no certainty or use in science.

Some substances, as all stones and earths, and the solid parts of plants and animals, remain solid at all natural temperatures of the atmosphere; and a few of them, as the simple earths, do not, without mixture with other substances, yield to the greatest heat of common fires and furnaces.

Among the metals, platinum and malleable iron, that is, iron which can be beaten into shape by the hammer, do not become perfectly liquid by heat, though they are so much softened that they stick together, and any number of pieces may be united into a whole by the process called "welding." They are the only metals which have this

property, and it is in many respects more useful than the property of complete melting. Thus we see that, when a substance wants some useful property, it has another instead, which is equally important, if we can find it out.

Glass cannot be made quite liquid, but retains a considerable degree of toughness, so as to admit of being drawn out into very fine threads; and this is one of the most valuable qualities of it; for a plain vessel can be made of glass in less time, and with fewer and simpler tools, than of any other substance.

Malleable iron may be changed into cast iron, by combining it with a certain portion of charcoal. So that malleable iron is the purest iron, and cast iron a compound of iron and charcoal. If sufficient charcoal could be combined with it, the iron would become black lead, the same as in drawing-pencils, only there is a little oil in that to render it less brittle.

When malleable iron is combined with a smaller quantity of charcoal than that which converts it into cast iron, it becomes steel; and the steel may be either weldable steel or cast steel according as there is less or more charcoal combined with it. Upon this principle the mere surfaces of iron articles are often converted into steel, while the greater part remains in the state of iron. These are said to be "case-hardened." They have some advantages over both iron and steel; they have the toughness of iron, and at the same time the polish and colour, and some of the stiffness of steel. Fire-irons are often case-hardened.

If the state in which any body exists at the general or common temperature of the atmosphere, and which is, on that account, familiarly called the *natural* state of the body, be the state of solidity, then the degree of heat, or the temperature, at which it becomes liquid, is called its *melting point*. But if the body is naturally liquid, the degree of heat at which it becomes solid is called its *freezing*, or *congealing*, or *concreting point*. Thus, of the metals generally, we speak of the melting points, and we speak of the freezing points of water, and all other liquids

that can be frozen by any means, either natural or artificial; and of the congealing or concreting points of oil and other substances which become solid by exposure to cold.

Quicksilver is the only metal which is a liquid in what we call its natural state; and it becomes solid, and may be hammered on an anvil at—39°, that is, 39 below 0, of the common thermometer, or 71° below the freezing point of water. This is much below any natural temperature known in Europe; but in the extreme north of the American continent, according to the observations of Captain Franklin, the temperature is more than 80° below freezing during the months of November, December, January, and February, so that, in that district, mercury must be a solid for at least four months every winter. This may seem singular and even incredible to the uninformed natives of the temperate climates of Europe; but the existence of water in a state of ice would seem just as incredible to the natives of the warm plains of the tropical countries. There have been instances of children sent from the West Indies to Britain for their education, who, when they first went out and saw snow on the ground, came running in a paroxysm of joy, and calling to the people of the house, to come out and "*gather the salt.*"

Section LXX. Thermometers.

There are few bodies which pass from the solid to the liquid, or from the liquid to the solid state, at the same temperature with each other; and there are, perhaps, as few that require the same degree, or, as it is sometimes called, the same "quantity of heat," to keep them in the one state or in the other.

The solid state of all bodies is the state of least latent heat; but although some bodies, as mercury, assume that state only at very low temperatures, and others, as pure alcohol, or spirit of wine, do not assume it at any tempe-

rature with which we are yet acquainted; we are not thence warranted to conclude, that any body whatever, is, or can be, in a state of absolute cold, or totally exempted from the action of heat. In other words, we can assume no substance whatever as a thermometer that can reach the bottom of the scale of heat.

Indeed, it will readily be perceived, from what has been said of the impossibility of in any way measuring heat, or finding out anything about it, further than its effects on other substances, that no thermometer can be a measure of *heat* in itself, and without reference to some body or substance.

Heat, which is indicated by any common thermometer, is nothing more than the expansions or contractions of the substance of which that thermometer is made; and as bodies in the gaseous or the liquid state are much more susceptible of changes of volume by changes of heat, airs or liquids are commonly used for thermometers.

Air thermometers are the most delicate; but as air is invisible, the changes of its bulk can be seen only by making it act on a liquid; and as all liquids are heavier than air, and most of them partly pass into vapour in air, air thermometers are liable to many inaccuracies, and they are seldom used for common purposes.

Mercury and spirits of wine are the liquids most frequently used. Mercury freezes or becomes solid sooner than spirit of wine; but it does not evaporate or pass into the state of vapour so soon. Both substances thus have their advantages; but mercury is, on the whole, the best, as it does not pass partially into vapour at such low temperatures as spirit of wine, which begins to evaporate silently before it comes to the heat at which it boils.

Everybody knows the form of a common thermometer and the manner in which it acts. It is a little hollow ball of glass, with a stem, having a small bore of uniform diameter throughout its length, but closed at the end opposite the ball. The thermometric liquid, that is, the mer-

cury or the spirit, fills the ball and part of the stem. The glass is, in fact, a mere case for the instrument.

These tubes are a very striking proof of the advantage that has been derived from the discovery of making glass. No substance but a transparent one would do for holding the liquid of a thermometer; and no natural transparent one would do, excepting some of the crystallized stones. To make a good thermometer-case of any of these, even of rock crystal, would, if at all possible, be very difficult and very costly—so much so, that the instrument would cost as many pounds as the glass one does farthings, and be no better, if even as good.

But when glass is softened by heat, it is more easily moulded than dough; for if a little bit of it be taken upon the end of a hollow tube, and blown gently into, it instantly forms a hollow ball, or it may be drawn out into a tube, the opening of which is a perfect cylinder, and of the same diameter throughout its whole length. Such, indeed, is the ductile and docile nature of the glass, that the thermometer is made in half the time that one could describe it. Glass has the advantage over every substance in forming a beautifully smooth surface, whatever may be its shape.

It is in those connexions of the different parts with each other that we best see the nature of science; and it is no exaggeration to say, that the sciences are more indebted to glass-making than to any other cause whatever.

When the ball and tube are made, the liquid is put in, and the whole heated to as near the evaporating point of the liquid as possible, because then it has the greatest bulk that it can have in that state. The end of the tube is then closed by melting the glass by heat, which is called sealing it hermetically; and in order that this may be the more easily done, a little bit of the end of the tube is drawn out thinner than the rest.

After the tube is closed, it is allowed to cool gradually; and as it cools, the liquid sinks down in the tube, leaving

part of it empty. The size of the ball must be regulated to that of the tube; for if the ball be too large, the liquid sinks down into it altogether, and the instrument is useless at low temperatures. On the other hand if the ball be too small, the liquid does not sink low enough, and the instrument wants range, or is useless at high temperatures. The proper adjustment is a matter of experience; and can be made only by those who have practised the art.

When the thermometer is made, the next process is to find a scale to it; and that scale is made from the degrees of heat at which some well known substance passes from a solid to a liquid, and from a liquid to a vapour. These are, in the same state of the atmosphere, always the same in the same substance; and thus, for whatever substance they are taken, they are fixed points; and that substance is made the standard with which all other substances are compared.

No substance can be better adapted for this purpose than water, because it is the most abundant of liquids, and because it both freezes and evaporates, or boils and is converted into vapour at moderate degrees of temperature, which yet comprise within their range very many of the natural operations that take place at the surface of the earth, and also a considerable number of the processes in the arts. The thermometer is therefore plunged into water, which is just freezing, or ice or snow, which is just melting naturally when exposed to the atmosphere, and a scratch made on the glass tube opposite the surface of the liquid in it, and that is the *freezing point*. Ice when formed, or at least the air by which ice is surrounded, may be cooled much lower than that, but ice cannot exist at a higher temperature, unless under circumstances different from those at the common surface of the earth; and therefore, for all ordinary purposes, this point may be reckoned a fixed one.

The freezing point being marked, the bulb of the thermometer is plunged into boiling water, and the instrument

kept there till the liquid in it will rise no higher; and then a scratch is made on the tube opposite the surface of the liquid, and that marks the *boiling point.* This point can be obtained only with mercury, as spirit of wine passes into vapour below the temperature at which water boils. The boiling point is a fixed one, because water cannot be made hotter in the liquid state, when exposed freely to the air—that air having the same pressure.

The atmosphere is subject to constant variations of pressure or weight, which are called *barometrical* changes, because they are indicated by an instrument called a *barometer,* or "weight measurer." If the thermometer is wanted for very nice and delicate operations, the barometric state of the atmosphere must be carefully attended to; and in instruments that have even moderate claims to accuracy, the freezing and boiling points must be determined when the pressure of the air is what is called *mean pressure,* or otherwise there must be an allowance made for any variation.

When the thermometer is prepared thus far, it divides the range of temperature into three parts answering to the three states of the standard substance, water. All temperatures below freezing relate to water in the state of ice (or of snow, which is ice in the form of crystals); from freezing to boiling, to water in the liquid state; and all above boiling, to water in a state of vapour. It must not however be understood that these apply to water in a perfectly detached and separate state, in which there is nothing to interfere with the action of heat upon it. They refer to it under natural circumstances, in which the heat has to overcome the gravitation or weight of the water, and also the pressure of the atmosphere.

Section LXXI. Graduation and Scales of Thermometers.

When the two fixed points with reference to water have been determined, and marked on the tube of the thermo-

meter, the next thing to be done is *graduating* it, that is, applying to it a scale of equal parts, which are called *degrees*, and graduating is simply dividing into degrees. The scale, that is, the number of degrees that shall be between the freezing point and the boiling point, is purely arbitrary; that is, it may be any number that the maker of the scale pleases.

The scale generally used in British thermometers is that called Fahrenheit's, from the inventor. It contains 180 degrees, or equal parts, between the boiling and the freezing points; and the scale is continued beyond these both ways, as far as may be necessary. It is, of course, useless to carry the scale above the boiling, or below the freezing, point, of the liquid in the thermometer, because, higher than the first, or lower than the second, of those points, the instrument would be of no use.

When Fahrenheit lived, the greatest cold known was that produced by the melting of a mixture of snow and common salt; and accordingly that was taken as the beginning of the scale, and when the degrees are numbered, that is marked 0 or *zero*. It must not be understood, however, that the 0 in the scale means that there is no heat, as the 0 in arithmetic means that there is no number; for there have been discovered many degrees of heat lower than that, and, as has been said, there is no reason to suppose that the lowest has been attained, or is attainable. There is, in fact, no beginning or end of the scale of heat, in whatever way we divide it; and, therefore, as we must begin our numbers somewhere, one point is just as good as another. The freezing point of water would have been more natural than the artificial mixture of snow and salt, and it is adopted in some of the scales, but it is not worth altering in the others.

The cold produced by the mixture of salt and snow produces a depression of the liquid in the tube of the thermometer equal to 32 of those degrees or equal parts, of which, as we have said, the range between the freezing and the boiling of water, under ordinary circumstances of

the atmosphere, contains 180. Thus the freezing point of water by the common thermometer is 32 degrees, and the boiling point of water 212, and any degree of heat indicated by that thermometer is the one hundred and eightieth part of the length of the tube, between the freezing and boiling points, whatever that length may be.

There are other scales besides that of Fahrenheit. Indeed the scale may be anything, so that the number of degrees between the freezing and the boiling point is known; because then any scale can be expressed in terms of any other, by a very simple calculation. Thus, the two scales of division most common on the continent of Europe, are those of Reaumur and Celsius, the latter of which is called the *centigrade*, or "hundred degrees" thermometer. In both of these the freezing point of water is taken as 0 or *zero;* and thence to the boiling point of water is divided into 80 degrees in the Reaumur scale, and 100 in the centigrade; and when those numbers are known, it is very easy to convert the heat, as expressed by any one of the three, into the corresponding expression for either of the other two.

The number of degrees in the same expansion of the thermometric liquid, namely, those from the freezing to the boiling point of water, are

Fahrenheit . . .	180
Reaumur . . .	80
Centigrade . . .	100

Or, dividing all these numbers by 20; 9 Fahrenheit, 4 Reaumur, and 5 centigrade, are all equal.

If any one number of degrees of any of these three scales be multiplied by the proportional number of any other of them, and the product divided by its own proportional number, the quotient will be the corresponding number of degrees of the other. Thus, the boiling point of spirit of wine, under the common pressure of the atmosphere, is 174 degrees of Fahrenheit, or 38 degrees below the boiling point of water. Let it be required to

express this in degrees of Reaumur and of the centigrade thermometer.

In comparing the scales, it must always be borne in mind, that Fahrenheit's scale begins 32 of its own degrees below the centigrade and that of Reaumur; and that therefore, if the degrees are *positive*, 32 must be subtracted from those of Fahrenheit before they are changed into the others.

This being borne in mind, let us take the boiling point of spirit of wine, 174, and change it into Reaumur and centigrade. Deduct 32 from 174, leaves 142 above the freezing point of water by Fahrenheit. Then 142 multiplied by 5 and divided by 9 will be the centigrade; and 142 multiplied by 4 and divided by 9 will be Reaumur. The first is $78\frac{8}{9}$ for the centigrade; and the second is $63\frac{1}{9}$ for Reaumur. Thus, though each of the scales is convenient enough in itself, they do not answer well in all cases for conversion from the one to the other on account of the fractions.

When the temperature is lower than that which answers to 0 or *zero* on any of the thermometers, the degrees are differently named. They begin at 0 and count downward, just as the other part of the scale counts upward from 0; and in order that the degrees below zero may be distinguished from those above, the sign — (*minus*) is put before them: thus — 2, — 3, &c.

There is some caution necessary as to the use of this *minus*. In arithmetic, a *minus* number means a number to be "taken away,"—a number which has the same effect as if it were all that it expresses, "less than nothing." Thus — 5, would make any other number or numbers 5 less. But in the degrees, it merely means "below 0;" and in the scales of Reaumur and Celsius, "below the freezing point of water." In Fahrenheit's scale, it means "more than 32 below the freezing point of water;" so that the clearest way of expressing — (*minus*) degrees of Fahrenheit is to add 32 to the number, and insert the words "below freezing:" thus, — 17, which means 17

minus, or below 0, is "49 below freezing;" and so of any other.

Section LXXII. The Measures indicated by Thermometers.

We are accustomed to say that the numbers indicated by the thermometer are degrees of heat; but we must take care that we do not deceive ourselves when we use this expression. Of degrees of heat, as measurable in itself, we do not know anything; and the degrees shown by the thermometer are not even definite measures of length. If the ball of the thermometer and the tube do not bear exactly the same proportion to each other, the distance from the freezing point to the boiling point of water is not the same in any two thermometers; and as the space between these is always equal to 180 degrees of Fahrenheit's scale, of course the individual degrees are of the same length only when that interval is the same.

In any one thermometer, though we make the several degrees all equal lengths or portions of the scale, we are not thence warranted in saying that they indicate equal portions of absolute heat. They merely indicate equal lengths of that part of the thermometrical liquid which is in the tubular part of the thermometer; and thus, at different degrees of heat, they do not indicate equal expansions or contractions of that liquid. The whole of the liquid (the mercury for instance) is that which is expanded by increase of temperature, and diminished when the temperature is lowered; but the glass in which the liquid is contained is subject to changes of bulk, and consequently of capacity, from the same causes; and were these to take place to the same extent as in the contained liquid, that liquid would not rise in the tube of the instrument at all. But the expansion of the glass, and consequently the capacity of its cavity, is much less than that of the mercury or the spirit of wine; and, therefore, the rise or fall of either in the tube, shows the difference of their expansion or contraction pretty accurately.

The larger the volume or quantity of liquid is, the smaller must be the addition made to it, or the change of its bulk, by an equal rise in a tube of uniform diameter; and, therefore, as the degrees are all of equal length throughout the whole range of the scale, the expansion answering to a degree becomes less and less the higher the temperature is. No doubt the difference is very small; but still it must be understood, that we not only do not know what the absolute heat is which a degree of the thermometer indicates, but also, that it does not indicate perfectly equal expansions of the mercury or other themometric liquid.

These considerations do not prove that the thermometer is inaccurate; they only warn us against believing that it has properties which it cannot, in the nature of things, possess. If the thermometer is properly made, it shows degrees of expansion which, though not absolutely equal throughout the whole range of the scale, yet differ very little, and differ gradually, so that for several successive degrees the difference is imperceptible. Certain of these degrees answer to certain states of other bodies, as 32° of Fahrenheit to the freezing, and 212° to the boiling of water; and the way in which changes of state in other bodies agree with, or are measured by, the scale, is found by actual trial.

We first get the state of the thermometer answering to that of the body by actual trial, and when once we have found that, we can always infer the state of the body by seeing the state of the thermometer as applied to it. Thus, for instance, we may lay it down as a general truth, that when the air at any place has a lower temperature than 32 of Fahrenheit, water cannot remain permanently at that place in any other state than that of ice or snow; aud also, that if the air at any place has a temperature higher than 212°, water at that place must be changed into vapour; and further, that where the air is at any degree between 32° and 212°, water must remain fluid.

If we find this general law violated, we must seek for the cause of the violation in something that can counteract the natural tendency of the water. This may be done either by pressure, or by the cohesion of some compound substance of which water forms part. Thus, the watery juices in the leaves and stems of plants do not freeze quite so readily as water exposed to the free air; but the more delicate the containing vessels are, and the more plentiful the water is in respect to the containing matter, the sooner the leaf freezes. The matured leaves of a common laurel stand severe frosts without injury, and those of the northern pines defy months of incessant and severe cold; but few vegetable substances are more easily injured than the young and succulent leaves of the laurel, when they have just expanded from the buds; and in early seasons, when the pines show green on the young shoots too soon, and a frosty night occurs, they, too, are nipped by it.

Up to a certain degree, the cold contracts the vessels of the leaf, and the juices are thereby compressed, which causes the disengagement of a little heat. But as the juice reaches the temperature at which it freezes, it begins to expand, and as the process goes on, the vessels, if they are tender and contain much juice, are ruptured and destroyed.

We have, in sea-water, an instance of the union of substances resisting the action of low temperature. Sea-water is a mixture of water with common salt and some other saline substances; and, independently of depth, tides, currents, and all other external causes, sea-water remains liquid at a lower temperature than pure water. Not only so, but the attraction of the water and the salt for each other shows itself at the upper confine of liquidity also; for though the water can be "boiled off," and the salt left behind (which is the way of obtaining pure salt for the table), yet boiling brine is hotter than boiling water.

A little reflection will show that this is just what we

have reason to expect. It has been mentioned that the mixture of snow and salt melts, and in melting reduces the temperature to 32 degrees below freezing, or to 0 of Fahrenheit's scale. This low temperature is produced by the tendency that the two substances have to melt and unite with each other in a liquid; and as the degree to which the temperature is lowered indicates a pretty strong action of uniting between them, it must follow that that action, or, which is the same, the effect of such action, cannot be overcome but by another which is more powerful.

When we study the operations of nature, we must be on our guard against being misled by analogies drawn from the conduct of mankind. They accommodate each other; power giving way to justice, and strength yielding to affection. But there is no accommodating in natural processes. The law there is the law of the strongest, and it is always obeyed; and so exactly proportionate is this obedience to the power of the law, that when they are properly understood, the one is found to be a perfect measure and exponent of the other.

Section LXXIII. General Law of Heat.

The general law of heat is to diffuse its action (and besides its action, or rather the effects of that action, we know nothing about it) equally through all bodies in all parts of their substance. As is the case with light, the action of heat always proceeds by the shortest course; and in bodies of uniform and homogeneous structure, its action is uniform.

But as it is only in the changes which it produces in bodies that the action of heat is known; and as the states and natures of bodies are in endless variety, and every variety, however minute, produces a difference in the action of heat, the practical investigation of the law is long, laborious, and intricate.

We have said that the state of solidity is, in all bodies, the state of "the least latent heat;" the meaning of which

is, that the cohesion, or force by which the minute and individually invisible particles of bodies are held together, and in the same relative positions with regard to each other, is less subdued by heat in the solid state than in the liquid.

Generally speaking, these primary particles are nearer to each other in the solid, and perhaps they are always so in the relation of particle with particle, though the whole of any measurable mass of the substance may occupy more space when solid than when liquid; that is, may contain less matter in the same bulk (in a cubic inch, for instance); and thus be what is called specifically lighter, or having less specific gravity.

The specific gravities of substances are the relative quantities of matter in equal bulks of them, and these are determined and estimated by their weights. Thus, if any bulk of water weigh one ounce, an equal bulk of copper will weigh about eight and a half, and one of silver ten and a half ounces; so that eight and a half and ten and a half are the specific gravities of copper and silver, that of water, at the mean temperature and pressure of the atmosphere, being one.

If the solid be homogeneous, there is reason to believe that the solid has always less bulk, and consequently greater specific gravity than the liquid; but if the mass be crystallized, the solid may have, and often has, the greater bulk, and the less specific gravity; and the difference is sometimes the greater, in proportion to the largeness of the mass.

Snow, which forms in the very cold climates when the atmosphere all around it is much lower than 32°, floats ou the surface of water; and is also specifically lighter than ice, which forms on the surface of still-water in warmer climates, when the temperature is barely below 32°. The obvious cause of this is, the vacancies between the crystals; and, for the same reason, if formed of water equally pure, ice always floats the farther out of the water, and is, consequently, specifically lighter the less

transparent it is. There are instances in which the ice-brash, formed by heavy snow falling in shallow bays of the sea at low water, has become so compacted, yet so buoyant, that it has pulled out of the ground stones of many tons' weight, and floated them to a considerable distance when the tide rose.

It is a common saying with those who live by the estuaries of rivers, where ice-brash which moves with the tide is formed, that when the thaw has advanced to a certain stage the ice sinks. And there is no doubt, that as it softens, the air escapes, and the mass becomes so much more solid and transparent, that it rises very little above the water and is less visible. The chief cause of its very rapid disappearance is, however, the fact of its being nearly immersed in the water. The very process of the melting cools the air to such an extent, that spiculæ of new ice are often seen forming on the exposed surface of a floating mass of ice, while the part in the water is in the progress of melting. A mass of ice which grounds at high water, and is left there, remains unmelted after all the floating ice is gone; and if, as sometimes is unfortunately the case, an iceberg be stranded on one of the northern isles, in the early part of the season, when the seasonal ice in the Polar seas breaks up, it remains long after the floating icebergs are dissolved, destroys the summer, and diffuses famine and misery around it.

Section LXXIV. Solidifying of Homogeneous and of Crystalline Substances.

The contractions or expansions of bodies when they pass from the liquid to the solid state by cooling, lead to some very important results in the arts. Bodies which cool into a perfectly homogeneous mass, may be said always to contract as they solidify; and, therefore, such substances do not answer well for being cast, as they never preserve a sharp impression of the finer figures of the mould.

Glass has this property to a very great extent, and this property is found to be a great disadvantage. If glass, in any considerable body, is cooled by exposure even to warm air, at least to air at an agreeable temperature to our feelings, it is so brittle that it cannot be applied to any useful purpose. If the common articles of glass were set on a shelf in the open air, just as they come from the hands of the workmen, they would not only not bear to be used, but the greater part of them, more especially the thick ones, would fly in pieces before they were absolutely cold. If artificially cooled, as by plunging them into cold water, when hot, they would burst into powder with a loud report, if the slightest scratch were made on the surface.

Prince Rupert's drops, with which boys sometimes amuse themselves, are made on this principle. They are tears of glass dropped into cold water, by which they are formed thick at the end which enters first, but terminating in a thin tail or fibre owing to the viscidity of the glass. This slender part is more annealed than the rest; but if it is broken, the concussion speedily communicates to the rest, and the whole flies to powder with a crash like a pistol. To have one of them so broken in the hand may not be dangerous, but it is very startling.

If glass were suddenly cooled, there is no doubt that it would take a sharp impression from a mould; but it is more certain that it would be too brittle for use, as it would burst with an explosion, on the least touch, in the same manner as Prince Rupert's drops.

The cause of this is worthy of a little consideration. The siliceous and metallic parts of the glass have a tendency to crystallize on cooling; but, at very moderate temperatures, this is prevented by the toughness given by the alkaline flux. The tendency to crystallization is of course strong in proportion to the rapidity of the cooling; and the toughness weak in proportion to the diminution of heat. Suddenly cooled glass, therefore, is not only

partially crystallized in its structure, but the crystallizing tendency is held in suspension, as it were, by the toughness of the other ingredients; and the moment that restraint is taken off at one place, the whole arrangement is disturbed, and the glass is shivered to dust.

Glass, therefore, to be useful, must be annealed; and in the process of annealing it shrinks, so that no natural sharp point or edge can be obtained; and thus, though the surface of moulded glass is really finer than any that can be given by artificial polishing, and the texture of the whole stronger, the same beauty cannot be given to it. The angles are always rounded off, and even the flat surfaces are curved and irregular.

Many attempts have been made to remedy this defect of moulded glass; and if they would answer, one of the most beautiful and cleanly articles would be reduced to a small fraction of its present price. But the hopes of complete success are small. Glass, from its very nature, cannot be formed into crystals large enough to be of any use; and it is not easy to see how the tenacity imparted by annealing, or even the sharpness of the figure could be obtained by pressure on the soft glass. Even though these were obtained, the surface would want smoothness and lustre, for it is its softness in the furnace that gives these. Many important improvements have been effected in the manufacture of all kinds of glass, since the repeal of the duties. The advantages to the public are not those only of reduced prices and a greatly increased consumption; but the impulse thus given to skill and enterprise has shown the applicability of this beautiful article to purposes hitherto unattainable; and which, probably, would never have been thought about under the oppressive restrictions of fiscal regulations.

The French have a method of giving sharpness to medals and other figures, in a compound metal which is cheap and easily melted, but which is too brittle for taking the impression of a die in the same manner as gold, silver, or copper does, in the common process of

coining or metal-stamping. These metals are comparatively soft, and they are tough, so that they yield to the blow of the die; but the coarse metal which the French use would go to pieces if struck cold.

The process to which they have recourse is called *Clichée.* Many of the easily fusible compounds, or alloys composed of tin, lead, antimony, and other metals, similar to those used for printers' types, begin to crystallize partially before the mass has acquired any general cohesion. In this state they may be stirred with an iron rod, and they seem curdled. The cause is, simply, that some parts of the alloy are much more fusible than others, and remain liquid after the others are partially crystallized. While the metal is in this partially crystallized, or curdly, condition, a die of cold metal, having the reverse of the intended figure sunk upon it, is made to descend on the metal, supported and surrounded by a strong pan, hollowed out to the shape, and to the depth wanted. The blow of the die forces the metal together, and the cold consolidates it at the same time, so that the impression is clean and sharp. But this method can be adopted only in the case of metals which fuse or melt at a low temperature, and of which some of the parts begin to crystallize before the others.

Section LXXV. Solidifying of Crystalline Substances.

In metallic substances, which have more or less tendency to crystallize as they become solid, the pressure of what is termed "a head of metal," is often sufficient to give considerable sharpness to the impression of a mould; but in order that these may have a very fine and smooth surface, the temperature must be lower than that at which heat would act on a metallic mould, or lower than would decompose some of the earthy salts, such as plaster of Paris (sulphate of lime.)

Printers' types are a familiar instance of casting a hard

but easily melted metal in metallic moulds; and in these the stalk or body of the letter is a sufficient "head" for giving sharpness to the face of the type.

The great body of type-metal is lead and antimony, but it is variously mixed with small proportions of copper, brass, or arsenic, and some of the type-founders are said to have secrets in the mixing of their metal. The great secrets, at least the properties most desirable in the metal, are that it shall melt readily and completely, that the hard and soft ingredients (which have different specific gravities) shall not separate, that it shall *set* or harden speedily in the mould, and that it shall neither be too soft nor too brittle when cold. In order to insure all these, both care and experience are required; so that, as is the case with all nice practical operations, little advantage would result from attempting minutely to explain it in words, even though this were the place for such an explanation. Every person claiming to be intelligent and well-informed should know something about the principles of these operations, but the practice is best left to those whose profession it is.

The moulds, or, as they are termed, *matrices*, in which the letters or faces of the types are made, are formed by steel punches. These punches are exactly similar to the letters and other characters; and they are struck into copper or soft brass, as far as the shoulder of the type. The impression so struck is the *matrix*. The mould forms the stem or body of the type, and it has the matrix with the impression at the bottom. Of course the letter in the matrix (only that it is hollow) stands in the same way as the printed impression from the type.

The workman, holding the mould with the matrix undermost, pours the metal into it from an iron ladle; and, as it very soon consolidates, the mould opens, and enables him to shake out the type, and instantly closes to receive another supply; the operation being performed so quickly that a man can cast at least three thousand letters in a day.

The little heads of metal are broke from the types, the ends are squared and grooved, the sides scraped even, and the angles of the shoulders taken off, all by very simple but very efficient machinery; and then the types are arranged ready for sale to the printers. The number of these types that are used is truly astonishing, and the beauty of their forms, especially the very small ones, is not less so.

Stereotypes are taken from entire pages of moveable types, in moulds of plaster, the types being oiled to make the mould separate. The entire stereotype, or "solid type" page, is then cast at once in the mould; but it is difficult to get the metal as uniformly hard as in the moveable types; and as it is a fourth copy after the punch, while the moveable type is only the second copy, the impression cannot be expected to be so sharp and fine. When, however, a great number of printed copies, at a cheap rate, is required, the advantage of stereotyping is considerable.

Though brass is an alloy (of copper and zinc) and granulates in becoming solid, it does not crystallize so as to form a very sharp impression in a mould. Indeed it may be considered a general rule among metals, that those which can be hammered into shape, either hot or cold, always shrink too much in cooling for coming clean and sharp out of a mould; and that the greater the degree of heat necessary for melting them, the less perfect they are when cast.

Bronze, which is an alloy of copper and tin, with or without other metals, is much harder than brass; but it is more stubborn and brittle; having in fact more of the crystalline structure. Although, therefore, it does not bear the hammer well, it answers much better for casting.

Cast iron has a structure considerably crystallized; and it consequently stands well to the mould, when that mould is well finished. But it requires a strong heat before it melts; and therefore the inside of the mould has to be

dusted with powdered charcoal, which, though it gives great hardness to the external crust of the metal, renders it black; and the surface cannot be brought to a polish without working through this hard crust into the softer metal.

But still, for common purposes, cast iron stands sufficiently to the mould, both for sharpness and for surface; more especially as it will not bear the common action of the atmosphere without decay, unless it is protected by paint.

There are not very many substances besides the metals, which are melted by heat and crystallized by the abatement of that heat without the union of some other substance in the previous state. The "stearine" of animal fat, which is found very abundantly in the larger toothed whales, and which may be obtained from the fat of many animals, by squeezing out the oil, is one of these substances. When obtained from the whale, it is called by the absurd, or at least the inaccurate, name of "spermaceti," or simply "sperm;" and when procured from other fat, as from that of sheep, it is called "composition," which is not more correct, as it is a simpler substance than the entire tallow, and obtained by a sort of "decomposition" of it. It is only when stearine is cooled rapidly and has not been overheated that it crystallizes; for if the cooling is very slow, the structure of it is annealed, as it were, and if it be subjected to a strong heat, under circumstances that prevent it from burning, it is converted into a very pure transparent, and inflammable oil, which burns very brightly in lamps, and with little or no smell.

Section LXXVI. Expansion of Solids by Heat.

Degrees of heat much lower than those requisite for melting solids, or changing them to the liquid state, affect their cohesion to a considerable extent; and this effect is not confined to solids which can be melted previous to the

separation of their parts by evaporation or combustion, but is found in all solids, except in cases where we can explain why it does not appear.

These expansions do not depend on the latent, or imperceptible heat of bodies, but upon their sensible heat,—upon that action of heat which they are disposed to receive from bodies at a higher temperature, or communicate to bodies at a lower. It does not follow exactly the law according to which they can be more or less easily heated, neither does it follow that in the order in which they can be melted. In most instances there seems to be a relation to the facility of heating and melting; but in others there is none, or if there is, it is modified and counteracted by the internal structure of the bodies.

With moderate changes of temperature, the expansion of solids is very small, not worth attending to, unless in very nice operations. The results given by different experimenters are different, partly owing, no doubt, to little differences in the substances, and partly to differences in the methods of making the experiments. The following are the approximate results of linear dilatation for a few substances—the range of temperature being from the freezing point to the boiling point of water :—

Lead, from 32° to 212°	expands	1 part in	351	nearly.
Tin (Cornish)	do.	1 part in	462	—
Silver	do.	1 part in	524	—
Brass	do.	1 part in	532	—
Copper	do.	1 part in	581	—
Gold	do.	1 part in	650	—
Iron	do.	1 part in	846	—
Steel (tempered)	do.	1 part in	807	—
Steel (untempered)	do.	1 part in	927	—
Glass (various) the mean	do.	1 part in	1120	—
Platinum	do.	1 part in	1131	—

These quantities of expansion for the whole range from the freezing to the boiling point of water are very small; but some of them are applied to important purposes.

Thus, in the compensation balance of the watch represented on page 32, the arms and the inner parts of the segments of the ring are made of steel, and the outer parts of the segments, which are riveted to the steel at the end of the arms, and fastened by the screws at the two ends, are of brass. As the steel expands with heat, the balance becomes larger, would throw wider, and the watch would go slower; but the brass expands more than the steel, and so bends the steel segments inwards, and the receding of the screws compensates the expansion of the arms.

The pendulum rods of clocks, when made of metal, are subject to the expansions and contractions of different temperatures. Thirty degrees difference of temperature will alter the rate of the clock about eight seconds in a day, slower if the temperature is warmer, and faster if it is colder; and as the difference is often more than that in a very short time, the time shown by the clock would not answer for nice purposes.

Pendulum rods of glass or good dry deal, which expand very little, and nearly to the same extent, improve the going of the clock. Compensation pendulums are, however, the best for insuring uniformity in the rates of clocks. These are either made of two metals, brass and steel, or of a common rod with a vessel of mercury for the "bob," or weight at the end of the pendulum. The rods, or sometimes a set of tubes, one within the other, are so arranged that the commencement of one set is from the point of suspension, and that of the other from the bob; and as their ends bear upon each other, one set tends to raise the centre of oscillation just as much as the other set tends to lower it. When the mercurial bob is used, the instrument is more simple, and in some respects preferable. Only one rod is required, and the expansion of the mercury (which is 1 in 50 between 32° and 212°) raises the centre as much as the expansion of the rod lowers it. Such a pendulum, also, admits of a very nice and accurate adjustment, by increasing or diminishing the quantity of mercury.

Section LXXVII. Specific Heat of Bodies while they remain in the same state.

Though we have no means of knowing the absolute action of heat (or the quantity of heat, as it is sometimes called) in any one substance, inasmuch as we cannot find out what action of heat may remain at the very lowest temperature that we can procure; yet we can compare the effects which different degrees of heat have on different substances. We can also find by immediate observation, the degree or action of heat necessary for changing any substance from the solid to the liquid state, or from the liquid to the gaseous. But what we purpose in the mean time to notice is, the different actions of heat, which without any change in the state of bodies are necessary to give to different ones the same apparent indications of thermometrical temperature.

This is sometimes called the *capacity for heat* in the bodies. It is, however, the capacity of bodies for *resisting the tendency of heat to raise their temperature* which is really meant; for that which takes the greatest heat from other bodies to raise it to a certain higher temperature by the thermometer, or communicates the greatest heat to other bodies, upon being reduced to a certain lower temperature, is the one which is said to have the greatest capacity for heat, or the greatest specific heat.

The comparative specific heats of different bodies are as the relative quantities of heat necessary to produce equal thermometric changes in them. The subject is one of considerable importance in the economy of warmth; but it is attended with some difficulties. Most bodies, when they are mixed together, so act upon each other that either a portion of the heat that was previously latent becomes sensible, or a portion of that which was sensible becomes latent. Thus, in the mixture of spirits with water, some heat is produced, by the mutual action of the two upon each other, the result being a small dimi-

nution of bulk. If the mixture be sulphuric acid (oil of vitriol) and water, the heat is still greater; and there are instances in which it is accompanied by great heat and light, amounting to combustion or explosion. On the other hand, if common salt be mixed with water, apparent cold is the result; and the mixtures of some other substances produce very intense sensible cold; but all these cases are attended with changes of state, to a greater or less extent, in some of the substances mixed; and these prevent any certain conclusion from being arrived at respecting the specific heat of any of the substances.

If the experiments are made by means of mixtures of equal quantities at different temperatures, which answers very well when we are sure that the bodies do not act on the state of each other, the resulting heat will be below the mean when the body of the least capacity is the warmer; and above the mean when that of most capacity is the warmer; and double that will be the heat which the body having the greater capacity has communicated to the other; and consequently double that again must be the difference of their capacity for heat, or of their specific heat.

The relative specific heats may also be determined by exposing the bodies, at the same temperature, in the same manner, to the same substances which do not act chemically upon them, and noticing the times which they require to sink to the same lower temperature; and the times will be the measures of the specific heats, very nearly.

The action of sensible heat upon bodies always tends in some degree to alter their cohesion, to weaken it in all cases when the heat does not remove some part, the effect of which, while it remained, was to weaken the cohesion of the whole. The heat which is felt or apparent, is the result of the resistance of the body to the loosening or disturbing of its cohesion; and different capacities for heat are the effects of different resistances. But we must not confound the resistance that is offered to heat with the resistance which one piece of solid matter offers to another; for one piece of solid matter cannot pass through

another without making a hole or fracture, and it acts directly only upon those parts that are near its passage. An axe cuts its notch, a saw tears along its line, and a bullet pierces its hole, with little or no effect on the board at less than an inch distant.

Heat, on the other hand, penetrates through the solid, and through it all equally, if all the parts are exposed to an equal degree and continuance of heat. It enters between the very particles—those atoms that cannot be seen separately by any eye or any microscope; and whether the body be homogeneous, as we may say of air, or liquid water, or carefully annealed glass, or crystallized with a peculiar arrangement of its particles about certain axes, it in so far makes particle recede from particle; or, which is the same, it makes every particle repel those around it, in whatever direction they are situated.

Mechanical action pushes or draws a mass of matter, greater or less according to its intensity, but it does so only in one direction, that of the force; or if the direction is changed, there is always a cause for the change, and the effect of the first force is less than when it is direct. Thus, a force coming from the north acts directly south, as long as it acts alone. If an equal one from the west act along with it, the resulting force will act toward the south-east; but as part of the energy of each force will be exhausted in changing the direction of the other, their joint effect must be less than the sum of their separate effects.

This becomes quite evident, when we consider that for every foot the force from the north pushes southward, the equal force from the west must push a foot eastward; and thus, at the end of any time, whatever it may be, a body moved by the two forces will be found at the angle of a square, opposite to the point from which it is moved, and having its parallel sides in the directions of the forces.

Also, if the two forces act at a right angle, but are not equal, the body moved will move fastest, and also most directly in the line of the most powerful one; so that at

the end of any given time, the body moved by two unequal forces will be found at the angle of a parallelogram (a four-sided figure with the opposite sides equal and parallel) opposite to the point at which it was first acted on; and the parallel sides will be in the directions of the forces, and the length of their sides in proportion to the intensities. Thus, if the force from the north is double that from the west, the body will move twice as far southward as it moves eastward.

But the forces may act at any angle; and the resulting force will still be in the direction to the opposite angle of a parallelogram, of which the parallel sides are in the directions of the two forces, and having their lengths proportional to the intensities. Thus, if the current of a river runs east, and the wind blows from the north-west at such a rate that it carries a ship as fast as the current does, the ship will cross the river in the direction exactly midway between the east and south-east.

It is necessary to understand the law of mechanical action thus far, in order not to confound it with the law of the action of heat. It is necessary also to bear in mind, that the great and general resistance to mechanical action is gravitation; and that, when the consistency of a body on which that action is exerted is such that it neither breaks in pieces nor alters its shape, all the parts of it move on at the same rate, and at the same distances from each other.

The action of heat is very different. If begun at a point, it acts all round that point; and as long as the matter round the point is everywhere alike sensible to the action of heat, that action extends in a sphere. If heat is applied to one end of a metal rod, and prevented from reaching the other end by any means but through the substance of that rod, it will reach it in the same time, whether the rod is straight or crooked. Whenever, therefore, we find the action of heat propagated more in one direction than another, we may always be sure that there is a cause independently of the heat itself; for the specific

action of heat is always to loosen the cohesion of bodies, by producing a sort of repulsion between particle and particle, equally throughout the mass, and in proportion to the intensity of the action.

But though the action, as between *one* particle and *another*, cannot be regarded as having any mechanical effect, yet when this action extends through any measurable mass or quantity of a substance, and expands it, this expansion brings the result within the limits of mechanical change, both by altering the specific gravity, and by producing sensible or measurable motion. Thus, if one side of a piece of paper be held to the fire, the heat evaporates the moisture out of that side faster than out of the other, and it contracts and curls round. The same effect may be produced by rubbing it till it is warm. Toys are sometimes made of substances that expand readily by a small increase of temperature at one surface;—fishes, for instance, that curl up at both ends, and turn over, even with the heat of the hand on the palm of which they are laid. So also a loaf of bread, the expansion of which downward is resisted by the bottom of the oven, rises at the surface and spreads at the sides; and if it be enclosed in a tin, which does not expand so much or so rapidly as the loaf does, it forms a projecting crown over the sides of the tin.

If one of the ingredients of a compound expands more readily by the action of heat than the others, that one, by becoming specifically lighter, comes to the surface. Thus, the air which is contained in water, expands and rises to the surface, producing the noise called "simmering," before the water begins to be converted into steam; and after this conversion begins, the little bubbles of steam expand, and come to the surface, throwing that part of the water which is still liquid into a state of agitation. The air which is in shallow water exposed to the heat of the sun, and the gases that are produced by the decomposition of vegetable and other substances under water, rise in bubbles in a similar manner.

If the ingredients of a compound are of different specific gravities, the loosening of the aggregation by the action of heat, allows these differences to act, and the result is, that the lighter ones are raised to the top, and the heavier precipitated to the bottom. Thus, the fat of animal substances is lighter than the gelatinous parts, and these again are lighter than the bones; so that when these substances are, for a sufficient length of time, subjected to the heat of boiling water, the fat is raised to the top, where it remains in the state of oil, the gelatinous matters are held in solution by the water, and the bones remain at the bottom.

There is one little circumstance, connected with this very common and simple operation in domestic economy, which is worth attending to. The fat is a much worse conductor of heat than water, and it does not pass into vapour until the heat has reached about 600 degrees, which is 388 above the boiling point of water. Hence, a coat of fat on the surface of boiling water, enables that water to be heated to a much higher degree than if the surface of the water were exposed to the air. Therefore, if the object is to effect the speedy and economical decomposition of those substances that are soluble in hot water, that object is greatly promoted by leaving the stratum of fat on the top; and if in any case a greater degree of heat in water than that of ordinary boiling is required, it may always be obtained by covering the water with a stratum of melted fat, or of any of the fixed oils. If the heat is intense enough, there is no danger that the fat or oil will mix with the water or the substances which the water dissolves, unless some of those substances are of an alkaline nature so as to form soap with the fat or oil.

In some instances these separations of substances having different specific gravities, which take place in consequence of the expansion and loosening of the compound by heat, are very troublesome. In a very thick mass of type-metal which has been a considerable time in the liquid state, the lead, and the lighter and harder metals, are apt to sepa-

rate; and the lead is found at the bottom, too soft for any useful purpose, and the antimony and other lighter metals at the top, and too brittle.

So also in making the heavy glass which is best adapted for the object-glasses of large refracting telescopes, the lead, which is used in considerable quantity, is apt to fall to the bottom; and the composition is, in consequence, useless.

However slow may be the change which takes place in a solid or a liquid by the action of heat, that action can in most cases be so increased and continued that the cohesion of the substance shall be overcome, and it will pass from the solid state to the liquid, or from the liquid to the gaseous. When these changes take place, they are, in general, accompanied by a remarkable change in the latent heat, and the capacity of the substance for heat.

Section LXXVIII. Instances of Change of Bulk by Heat.

When bodies are subjected to the action of moderate degrees of heat, less than their capacities of resistance, their cohesion re-acts when the heat is diminished, so that when the same body is at the same thermometrical temperature, under the same pressure, it has exactly the same density. The force with which the body contracts in cooling is in proportion to that of the heat by which it is expanded; and when this is great, the returning force exceeds any that can be produced by mechanical means.

This principle is often applied with much advantage in the arts. Rings and hoops of iron, such as those used for the tires of carriage-wheels, are fitted on when hot and expanded; and when they are in their places, cold water is dashed on them, by which they are cooled; in cooling they contract, draw the wooden parts of the wheel together, and make the whole much more compact than it could be made by any other means. The partial charring of the surface of the wood by the hot iron is so far from

being a disadvantage, that it defends the wood from the corrosion that it would suffer from the rust of the iron when wet. The same principle applies to the fixing of wooden handles into tools; if these are put in when the iron is cold, they loosen though ever so much wedged; but when the iron is made hot, and suddenly cooled on the handle, it tightens.

The contraction of iron in cooling is applied to other purposes, as for instance, to the rivets by which plates of iron are united in forming large vessels, such as the boilers of steam-engines. The holes along the sides of these plates are punched out cold by a very simple, but, at the same time, a very powerful and clever machine. A heavy fly-wheel is put in motion by a man, or any other power, and when it is once set a-going, very little force keeps it in motion. Upon the axle of this wheel there is a small but strong pinion which works in the teeth of a large wheel on another axle, and turns it very slowly. Upon the axis of this second wheel there is an *eccentric* wheel, that is, a wheel which has the axis out of the centre, and of course has a larger radius, or distance from the axis, on one side than on the other. This eccentric wheel acts on the long arm of a strong lever, which turns on a centre, and as the wide side of the eccentric wheel comes against it, it is raised up slowly and gradually, but with great force. The punch is a strong piece of hard steel fastened to the under side of the short end of the lever, and exactly the shape and size of the holes. The plate to be punched is held on a piece of steel which has a hole in it exactly under the punch. As the eccentric wheel raises the long end of the lever, the short one is pressed down slowly, but with so much force, that the punch drives a piece out of the plate, and forms a neat and regular hole. When the long radius of the eccentric wheel has passed the long arm of the lever, and the short one begins to come round, that end of the lever falls, and the other, to which is attached the punch, rises. While they are up, the plate is shifted, and the punch descends

and makes another hole; and so on, as long as the machine is worked.

The use of heat in the arts is an application of science; and in a country like Britain, where there are so many steam-engines, and the boilers of those engines, from the short time they last, are the most expensive part of the engine, it is very valuable. Let us give a rude guess at the value of the foregoing punching process:—

Say that two men are required, one to turn the fly-wheel and another to direct the plate under the punch; that the fly-wheel turns round thirty times in a minute; that every fifteen turns of it make one turn of the eccentric wheel; and that the long end of the lever is ten times the length of the short one. It is evident that the machine will punch two holes in every minute, or 120 in an hour. The wheel and pinion give a power of fifteen times the man at the fly-wheel; and the lever again multiplies that power by ten, so that the punch has a power of 150 men. The useful effect of a man turning a wheel, supposing him to exert the same strength in both cases, is about double that with a hand tool, and the loss of time in shifting the hand tool will make up for the friction of the simple machine under consideration. So that the machine does the work of 300 men, and requires only two. Say that the wear and tear of the machine and its furniture is equal to another man, and still the holes are punched for the one-hundredth part of what they would cost by hand labour.

The plates and even the rivets for steam-boilers are also machine made; so that the only hand-work is the riveting.

The rivets are driven in hot; they are short nails with flat heads, which are driven home; then the workman batters the other end into a second head with his riveting hammer, which operation he completes while the rivet is yet hot; and as, with one man serving hot rivets, a second driving, and a third riveting, (the second holding on with his hammer in the mean time,) the work is very soon done, and the plates are not much heated. But as

the rivets cool, they contract in length and pull the edges of the plates together with immense force—force which no mechanical contrivance can equal.

The rivets so tightened do not slacken again when the boiler is heated by the fire and water and steam in using it; because, though the rivets do lengthen in proportion as they are heated, the plates expand and thicken at an equal rate, so that the joint is equally tight at all temperatures below that at which the cohesion of iron begins to give way; and this is much higher than any ordinary temperature of steam.

The expansion of glass by heat is often conveniently applied to getting the stoppers out of glass decanters when they stick fast. If a cloth wetted with boiling water is wrapped round the neck of the decanter, the neck expanding with the heat, more rapidly than the stopper, the latter will be loosened. Another, and a more effective, method, by which stoppers that have been set fast for many years have been removed, is thus performed. Fasten one end of a piece of stout string to some fixed point, the handle of a door for instance, holding the other end firmly in the left hand. Then make one or two turns with the string round the neck of the bottle and with the right hand move it backwards and forwards as briskly as possible. In a few minutes the friction of the string will heat the neck of the bottle, and by its expansion the stopper is liberated.

When metals have to be united by merely inserting one piece into a hole in the other, it always makes the tightest work, when the containing piece is hot. Thus, if a cast-iron bar is cast on the ends of forged iron rods, the whole will be as firm as if one solid piece; but if the bar is cast with holes, and the rods driven hot into these, they will loosen as they cool.

The contraction of iron in cooling is often employed as a direct mechanical power in cases where the force required is very great, and the space over which it has to act very limited. There is, indeed, no limit to this but the strength

of iron, and the stability of a fixed point or fulcrum from which the force can act.

Heat, by the way, shows us the difference between the merely mechanical strength of a substance, which resists its being broken or torn asunder, and the chemical force by which its ultimate particles maintain their arrangement, or return to it, after being disturbed by the action of heat. The first always has a limit, but the second has none; and so, if the connexion were strong enough, the contraction of an iron bar in cooling would pull the globe asunder. Indeed, it is always the mechanical power that yields, by being overcome by the other.

Section LXXIX. Contraction of Metals as a Power.

The contraction of iron has sometimes been applied to pull entire buildings to an upright position, when the foundations at one side have given way. For this purpose the point of rest, which may be a number of anchors, or any other contrivance that will "hold on" against the strain to be given, is chosen on the side toward which the building has to be pulled. Long and strong bars of irons are fastened to the fulcrum, their other ends beiug screwed for a considerable distance, passed through the wall, and an iron, or other framing, placed on the opposite side, so as to bear equally on all that is to be moved.

The first operation is to place strong nuts on the screws without the frame, and heave them with wrenching levers or any other powerful mechanical means, till the iron bars and the whole apparatus are as tight as mechanical force can make them. But if the wall is very heavy, and settled in its inclined posture, the chance is that it will not move an inch, even with the utmost exertion of mechanical skill and force; and then is the time to arouse the giant—to arm the workman with the invincible strength which links together the invisible atoms of the iron.

A fire is kindled around the bars; and they are heated

nearly to redness, but not so much as to soften them. They instantly obey the action of the heat and expand; but they are prevented from lengthening towards the fulcrum, and so they push at their other extremities through the wall. The nuts are instantly turned again, and made as tight as before. The fire is then removed; the iron contracts, and either the apparatus tears with the strain, or the wall is drawn towards the position intended. But the resistance of the wall is merely mechanical—so many pounds weight of matter, for instance; and thus the strength of the apparatus can be made to exceed that. A bar of good iron, one inch in the cross section, will bear a strain of at least 64,000 pounds weight. A wall of solid granite, a hundred feet long, fifty high, and four thick, weighs about 15,000 tons, so that thirty-three bars, four inches square each, would bear the strain of moving such a wall.

After the bars have cooled, they are again heated; the nuts are heaved tight, and the bars cooled again; and these operations are repeated as often as may be necessary. It must, however, be borne in mind, that by this severe action the power of contraction in the iron is weakened. The repeated heating and cooling renders it soft, so that it does not contract to quite the extent that it expands. Some of the softer metals have this imperfection in a greater degree, as for instance, lead. When a roof covered with thin lead is exposed to the continued action of the sun during the day, with the alternating cold during the night, it puckers into wrinkles and folds. Zinc does the same, even to a greater extent, so that large gutters of zinc, exposed to the weather, very soon crack and admit the water, not because the metal is oxydized by the air, for the air acts less upon the zinc than upon some other metals, but because it expands more than it contracts, till it at last forms folds, which stop the regular progress of the future expansions, and so crack and split.

The method taken some years ago by M. Molard to restore to the perpendicular two walls in the *Conservatoire*

des Arts et Metiers, at Paris, though the same in principle, was different from that described. These walls were bent outwards by the pressure of the floors and roof. They were first united by iron rods, having nuts outside. The alternate ones were then heated with lamps, till they expanded and could be screwed up; and when the lamps were removed they contracted. The other set were then treated in a similar manner, and the operations continued till the walls were brought to the perpendicular. The rods were left to brace the building.

Section LXXX. Change of State in Bodies by the Action of Heat.

But though the force with which the particles of bodies return to each other, after the action of the heat that kept them asunder has ceased, be greater than any mechanical force or resistance with which we are acquainted, it is less than the action of heat, and sooner or later it must yield to that.

Water is the substance which is most easily examined in all the three states, and it is one of the most abundant substances, and also one of the most useful both in the economy of nature, and in the arts; therefore it is the one most convenient for explaining the phenomena of change of state, as produced by the action of heat.

If water is wholly or nearly protected from the action of the atmosphere, it does not freeze at 32°. In a vessel with a very narrow mouth, it may be kept liquid at 21° or 22°, and, under a coating of oil, it may be cooled as low, if not lower. It is worthy of remark, that in these cases it expands nearly in the same ratio as in freezing; and that though it may be moved or stirred about, a tremulous or vibratory motion soon makes it freeze. This tremulous motion—a motion something like that of a boulting machine, allows the different attractions of particles and pieces of matter to act more powerfully than when the whole is at rest, and under the influence of gra-

vitation, or than when the whole is moving, however rapidly, in the direction of any force. Miners are aware of this, and so they shake the pounded spar and ore in baskets or boxes, adding water to facilitate the motion of the pieces; and the consequence is, that the light spar is soon found on the top, and the metal at the bottom. The process of washing gravel and gold for the diamonds and auriferous earth contained in them is similar; and so is that by which seeds are often cleared from chaff. The earthy matters with which wheaten flour is sometimes adulterated may be detected by an operation of the same kind.

These general coincidences, when we see them clearly, are always very valuable, as they bring many facts under one general principle, which serves as an artificial memory of the whole; and it is curious, that the same sort of process which enables the parts of a mixture to follow more accurately the law of their specific gravities, should enable the particles of the same substance to follow more readily the law of their solidification.

There is something further. Rain-clouds form when one current of the air sets contrary to another; and they form in the tremulous or vibratory parts of the air, which are not going either way. It is true, that when portions of air at different temperatures are mixed, the capacity of the mixture is not so much as that of the two portions unmixed; but, as we find that a vibratory motion of the particles of water disposes them to unite into ice, we have no reason to doubt that the same kind of motion must dispose the particles of the aqueous vapour in the air to unite into drops.

If water at a very low temperature (say 21°) be made to vibrate, it freezes, and rises to 32°; and many of the metals, when they are exposed to cold in the melted state, fall to a temperature a little lower than that of which they harden; and then immediately rise to that and become solid.

This may be pleasingly illustrated by the following experiment. Prepare a hot saturated solution of sulphate of

soda (Glauber's salt) and put it into a small glass bottle which must be securely corked, or the air excluded by covering its mouth with two or three folds of moistened bladder. Let the bottle be put in a cool place, where it will not be agitated. When the solution is cooled down to the temperature of the surrounding atmosphere, if the cork be suddenly withdrawn, or the covering of bladder (which on many accounts is most convenient) pierced with a pin or other sharp instrument, the liquid will most probably immediately crystallize, and in a few seconds become a solid mass. But if the admission of air be not sufficient to induce instant crystallization of the salt, imparting to the liquid a vibratory motion will generally effect that object, or it may be done by dropping into the bottle a small particle of any solid substance. The moment that, by any of these means, crystallization commences, the temperature will be found to rise several degrees.

When ice is melted, there is a great absorption of heat; equal at least to 140° of the thermometer. This is easily ascertained by mixing ice with hot water and observing the temperature of the resulting liquid. This has been done with ice at 32°; and it took an equal weight of water at 172° to melt the ice; the temperature of the mixture being only 32°. It is evident, that in this case, the melting of the ice required the 140° of heat of which the warm water was deprived. The experiment has been repeated in a number of ways, and the result has been nearly the same in all; so that we may regard it as a general and established truth, that when any weight of ice is melted into water, a portion of the action of heat equivalent to that which would raise an equal weight of liquid water from 32° to 172°, that is, 140° has been obtained from some other source, and has ceased to be apparent to the senses, or to the thermometer. We can hence see why ice melts so slowly, even in an atmosphere far above the freezing point; and why snow-water is so intolerably cold, even on a sunny day, nay, even when it is melting at or on the fire. But we shall have to consider these

points, and some others connected with them, in a future section.

The same result may be obtained by reversing the operation, and observing the degree of heat which becomes sensible when a body passes back again from the liquid to the solid state. With water this is not so conveniently done as in those metals which do not require a very high temperature to melt them, and also in some other substances, such as sulphur and wax; yet, when the heat at which the body melts is greater than 660°, which is the boiling point of mercury, our experiments become vague and inconclusive, as we cannot immediately apply a thermometer.

The portion of heat which disappears, or ceases to be discoverable by the thermometer, when a body passes from the solid state to the liquid, is called its 'heat of fluidity.' The real definition of it is, the heat which is necessary for so overcoming the cohesion of the particles of a solid, as to enable that solid to become and remain a liquid. This heat, though it is no more discoverable by the thermometer, than that which is called the *latent heat* of solids, and upon which all the degrees and modifications of solidity observable among solid substances probably depend, must be understood to continue in operation as long as the substance which is melted, or liquefied by its energy, remains liquid.

It does not destroy the power of solidification, for this remains in the liquid just the same as in the solid, unless there has been a decomposition, or a new compound formed—something separated from the solid, or something added to it. The operations of nature do not destroy either matter or action; though to our perception both may be changed from visible to invisible, or from invisible to visible. When the weather is warm, we lose sight of the attraction of congelation in the particles of water of the pools and streams, which during the severe cold kept them sheeted over with ice; and when the drought is of long continuance, the shallow waters themselves are gone.

But they are not lost. The matter has merely changed its state in the one case, and its state and place in the other.

As little, after the season of drought is over, and those general laws of nature, of which we can but partially see the operation, bring a change, can we say that the results are the effect of an immediate creation. It may be, that evaporation has apparently ceased, that the air is more than usually clear and transparent, so that a person unaccustomed to observation would believe that the weather were more firmly set for drought than ever. Yet a little cloud will come, we know not whence, and it will grow and grow, till the whole canopy of the sky is shrouded; and anon the lightnings will flash, and the thunders roll, and a deluge of rain will fall to the ground. But still, though we see but a part of the process, these things are not new; they are the consequences of former events; and those again of others; and if we endeavour to trace the chain, we find that it approximates toward that First Creation, in which nature, with its varied processes, was begun and perfected. And, when we study the matter aright, we must admit the conclusion, that not one atom of the matter which God has created, and not one tittle of the energy, or force, or capacity for assuming appearances with which He has endowed it, can perish, until it has accomplished the pleasure of his will, and He shall, in the fulness of his own time and pleasure, affix to it other laws, or assign to it other purposes.

This heat of fluidity has no effect whatever on the gravitation of bodies, and not much on the specific gravity of most bodies that can be melted without increase or diminution of their substance or quantity of matter. It merely loosens the cohesion of their particles, so that they move freely in every direction, and, unless in so far as gravitation is concerned, yield to the smallest possible force.

Those substances which crystallize, or follow some regular law in the arrangement of their particles when they become solid, generally melt into the most perfect

and limpid liquids. Glass and iron have been already mentioned, as always retaining a certain viscidity or ropiness, in all temperatures below that at which their composition changes. The same may be said of oils and jellies, and all substances that harden into homogeneous masses. So that the softening of the mere aggregation of the parts, and the suspending of the regular attractions, are distinct operations; and it is in proportion as the cohesion of crystallization predominates over the mere aggregation, that the body is liquefied by the action of heat, without decomposition or separation of its parts.

Section LXXXI. Bodies in the Liquid State.

Perfect liquidity may be termed the neutral state of matter considered in itself; because in it the cohesion of the substance and the action of heat exactly balance each other. A perfect liquid is entirely homogeneous—neither by the eye nor the microscope can we discern the slightest variation of structure throughout its mass. It is equally divisible in all directions; and it offers no resistance but the resistance of gravity, unless in consequence of the action of something else.

As nearly as we can judge on so very nice a subject, its own aggregation follows the law of its specific gravity; but this is modified by its general gravitation to the earth; and there are also surfaces for which almost every liquid has attractions, and others for which it has repulsions, though it is not easy for us to distinguish between the surface and the thin pellicle of air which may be between the liquid and that surface.

Every one who has watched a cascade of falling water, must have observed little brilliant drops of water dancing along the surface of the pool below, and even rebounding before they mingled with its waters. A similar experiment may be made with a glass of water. Take a glass nearly full, and notice the little rim of water, that stands higher than the rest, surrounding the sides. Then take a

very small tube, or any contrivance by means of which you can procure very small drops of water. Jerk a little on the rim, and it will bound away over the surface; and if you repeat the operation neatly and rapidly, you may have a number of little balls of water all in motion on the surface, dimpling it lightly where they strike, and bounding off again.

There is no doubt that, in these cases, the action of the air on the surface, both of the drop and the water, prevents their immediate union. Air keeps things wonderfully asunder, as one may find out who cuts a finger. If the edges of the cut are instantly brought together, and the air completely excluded, the parts unite without any other process, and with very little pain, by what surgeons call the 'first intention;' but if the air is admitted, the parts will not unite without 'granulating,' or forming new matter, and the edges of that make a seam or scar. The action of the air takes place wherever it obtains access, and that is almost everywhere that we can examine, and thus it perplexes us in our observation of the surfaces of liquids.

There is no doubt that it has a great influence on the formation of globules of mercury; for these are not long exposed to it before they lose their lustre, and are surrounded by an oxydized pellicle.

The volumes of liquids are changed by the application of heat in nearly the same manner as those of solids; and when the heat is withdrawn, they return to their former state. In water, and probably in all substances which crystallize, and of course have pores or open spaces between the crystals, the point of solidifying is not that of greatest density. The greatest density of water is at 39° of Fahrenheit, and below that it expands. But the expansion is very small, though the rate of its increase becomes greater as the temperature is lower. At 32°, the freezing point, it increases (without taking freezing into the account) 12 parts in 100,000. The expansion, at the temperature of 43°, which may be reckoned about the

average in the latitude of Britain, for water so deep as not to be much affected by the seasons, is about 5 in 100,000; and at 60°, which is not far from the average summer temperature of the immediate surface, it is rather less than 1 in 1000. At 212°, it is nearly 1 in 23.

The increase of bulk is of course attended with a proportional diminution in weight of an equal bulk; and though the extent of the changes is but small, yet the cohesion of water is so completely subdued that they act to their full extent, and water is, therefore, exceedingly mobile. The least diminution of heat brings up a fresh surface, till the whole has reached the temperature of 39°, which deep water never does in our latitudes; and hence with us deep water never freezes.

The remaining aggregation of parts, in consequence of which liquids form into little spherical masses, as dew does on the grass, or showers on the leaves of some vegetables, is feeble compared with the general gravitation of the mass toward the earth; and thus when there is any considerable portion of liquid, it always ranges itself according to the law of terrestrial gravitation; or, as we are in the habit of saying, finds its level. Except when disturbed by gravitation towards the common centre of the earth and sun, which is a point somewhere within the body of the sun, and the gravitation to the common centre of the earth and moon, which varies, but may be considered as between the earth and moon, and about 2000 miles without the body of the earth, the water takes the general curve of the globe; and the variations of its positions, or *tides*, as they are called, from happening at regular 'times,' promote rather than hinder the action of the waters in the general economy of nature.

SECTION LXXXII. EFFECTS OF LIQUIDITY. 1.

WHEN we reflect upon it, the property of liquidity appears to be so very important, that it alone would almost suffice

for the wonder of creation. The substances, simple and compound, that exist around us, are, to our observation, absolutely without number, and the kinds and degrees of cohesion by which the individuality of each is preserved, are just as numerous.

Now, if they were all in their solid state, wholly under the action of what may be considered their individual laws and principles, they would be so many individual creations, having no action or influence upon each other. Even though we suppose that in such a state they were subject to the same general laws of gravitation as they are now—that they were united into an earth by terrestrial gravity, and sustained in an orbit by gravitation toward a central sun; yet in such a state the globe would cohere and revolve in vain; for as every portion of matter in it would be in constant and undisturbed obedience to its own law, there could be no life, no action, no change; but the whole would remain in the fixed and dismal sterility of perpetual death. Even if the beams of the sun should light upon it and reveal it to the people of some distant world, the sight to them would be one of sadness, far worse than the sealess and streamless moon is to us. The non-existence of water in the moon may be as nearly demonstrated as the nature of the subject will admit, and it is corroborated by the fact that the mass of the moon, though the quantity of matter is only one-fortieth part, is denser than the mass of the earth, in the proportion of 11 to 9; yet the heat of the sun reaches the moon's rugged and rocky surface. The heating and oxydizing rays of the solar light are also absorbed there. Therefore, although there be no water, and consequently we can scarcely expect vegetables and animals at all analogous to those which are found on our globe, yet there is the action of heat; and no doubt there is melting and solidifying, and change from one state to another.

The distribution of light, both direct and reflected, is, however, so peculiar in the moon, that no analogy drawn from that body will apply to the earth. As the moon

always, with the small deviation which is called the 'libration,' or balancing, presents the same disk or face to the earth, it follows, that whenever the moon passes into the half of the orbit nearest to the sun, and loses the solar light, it must enjoy the light of the earth, as a moon, to a degree far more splendid than the moon is to us; whilst the opposite side, which we never see, can have no light but that of the stars and other planets, during all that portion of the lunation when it is turned from the sun. If, therefore, we suppose that the equator of the moon is a circle bisecting it in the plane of its orbit round the earth, the various points of that equator are all differently acted on by the light and heat of the sun; whereas the points of the earth's equator are all acted upon equally during every twenty-four hours; so that no conclusion can be drawn from the one body, which can directly illustrate the other.

When, however, the face or disk of the moon is viewed through a telescope of great magnifying power, it has the appearance of a mass of ruins. Those portions which seem dark, and have been thought seas, and are named as such in the maps or pictures of the moon, have rugged, uneven, and angular surfaces, utterly incompatible with any which a liquid could assume in obedience to those laws of gravitation which matter must obey in the moon as well as in the earth, and in every body that comes within the notice of astronomers.

Besides, as the quantity of matter in the earth is forty times that in the moon, and the force of gravitation toward bodies at the same distance is directly as their quantities of matter, the water on the surface of the moon, if there were any there, would be gathered around the centre of that hemisphere which is turned toward the earth, and also around the centre of the opposite one, just in the same manner as the waters of the earth are gathered toward the points nearest to, and at the greatest distance from, the moon. By reason of the greater attraction of the earth, these tides, or gatherings of the waters,

would be far higher than the tides of our oceans; and the highest one would be stationary, while the lowest one would alter with the position of the moon with reference to the sun. This last would coincide with the tide produced by the earth at the new and full moons, and be at right angles to it at the ends of the first and third quarters. These tides would consequently produce changes of appearance, which could not escape careful observers with good telescopes.

If any portions of the surface of the moon were liquid, they would, in certain positions of the moon, reflect light; and as the times when they did so could be calculated, the reflections could not fail to be observed. But though the annals of astronomy reach farther backward than perhaps those of any other science; and though the moon has always been one of the most interesting objects to all classes, there is no trace of any such reflection upon record.

On the contrary, there is no doubt that all the light parts of the moon are elevated, and the dark are hollows. The shadows, which change with the position of the sun, and are to a certain extent transparent, from the reflections of the elevated parts, show this; and when an outline can be obtained on any of the dark parts, it is always angular and uneven, as if formed upon beds and furrows of rocks, from which the surface-mould had been cleared away.

Seen through a good instrument, the lunar mountains are truly sublime; but it is a gloomy and dismal sublimity. They rise in vast peaks and masses, which no foot could ascend; and more resemble huge clusters of crystals than even the wildest mountains on the earth. Some of them, which must be equal to our hills in size, project laterally from the perpendicular sides of larger ones; and the bottoms of the dells, and bases of the precipices, are strewed with vast fragments, as if a world had been broken in pieces there.

From the most careful observations (those of Schroeter

are the best), it does not appear that the lunar mountains are higher than some of those on the earth. The most elevated are estimated at about five miles, which is nearly the same height as the most lofty summits of the Himalaya mountains between India and Thibet. It is also worthy of remark, that the very lofty mountains in the moon are all isolated peaks; while those that are in continued chains are of inferior elevation, seldom much more than a mile in perpendicular height, and generally less than a mile.

The most singular features of the moon's surface, however, are the pits or hollows. Some of them are nearly four miles in perpendicular depth; and others are forty miles across. These are always surrounded by elevated rims, and, in some instances, they rise up to lofty annular, or ring-shaped, mountains. But in the deepest of those cavities, there is not the slightest indication of a single drop of water, any more than there is on those shadowy and furrowed places that have been considered as seas. There is not, indeed, any appearance discoverable in the moon, that enables us to infer that water, or any other substance liquid at the common temperature there, exists now, or has ever existed, or had any influence in the production of those variations of surface, which we partially see with the unassisted eye, and are more clearly discovered by the aid of the telescope. There may be liquidity produced by fire there, for there have been occasional lights observed in the shadows, for which it is not easy to account except by the existence of volcanoes. The vast pits with their annular rims, the elevated peaks, and the huge fragments that are strewed around them, all point to a much more violent process of formation than that which takes place through the instrumentality of liquids; of which we shall see by-and-by that there are so many, and curious, and wonderful evidences in the earth which we inhabit.

SECTION LXXXIII. EFFECTS OF LIQUIDITY. 2.

In order to produce an impression of the importance of the liquid state of matter in nature's economy, by the most effective means, that of contrast, we have taken the moon as one of the subjects of comparison, in preference to comparing the dry parts of the earth with the humid, the land with the sea, or the rocks that have been produced by the action of fire with those that have been produced by the action of water.

It is usual to appeal to these terrestrial contrasts, for giving force and permanence to the impression of such truths; and it must be admitted, that some of the terrestrial contrasts, both permanent and seasonal, are abundantly striking. When we find an island, such as that of Ascension in the South Atlantic, or the Gallipagos in the tropical Pacific, composed of cinders and scoria and molten stone, and giving the clearest evidence that it has shot up boiling and burning from the depths of the ocean by the action of intense heat,—and compare it with those immense beds of shells and other products and deposits of the waters, which are found, not only in low and level places, but gathered into hills, and imbedded in rocky strata, at all elevations, from that of rocks under the sea to miles of altitude on the mountains,—we cannot but be struck with the contrast.

When, too, we compare the dry sterility of the Sindean desert in Northern India, with the rich plain of the Ganges, or the amazing fertility of the Terriani, where the springs from the Himalaya are in perpetual flow, the contrast is again great; and probably it is greater, when the vast desert of Northern Africa is compared with the rich and rainy districts around the bottom of the Gulf of Guinea.

The contrast of the streamless desert with the valley of Egypt, and its flooding and fertilizing Nile, has been remarked in all ages; as is proved by the appearance, on

Egyptian monuments, of the *Typhon*, or fabled demon of drought and desolation, and the emblematical representation of the Nile with the lotus-flower.

But still, none of these is a perfect contrast of liquidity and its total absence. The formation of the volcanic islands in the sea is as much owing to the water as the fire; and probably the shells which are found in the mountains have been both consolidated and raised to their present situations by heat. The Indian desert has its dew and its water-melons; and Sahara its clusters of palm-trees and its pools of water. These places are dry and unfit for human habitations, because they cannot be rendered productive by human skill and labour; but they are not wholly without the 'liquid element,' or that medium and moderate action of heat, which is necessary to the maintenance of the liquid state. It is true that in consequence of the small quantity of liquid, the little cooling action that it has, and the intense heat of the sun reflected and radiated from the dry and sandy surface, substances are raised in vapour there, which are not found in cooler, because more humid, places. But the Samiel, deadly though it be when it does come, is not the prevailing, or even a very frequent, wind in the desert; and, as it is more frequent in that part of the desert near to the Red Sea than in the more extended one farther to the west, it is not impossible that the waters of that sea, or some of those productions of which that sea is so full, may be instrumental in producing the pestilent visitation.

From the very fact of its being a wide desert of dry sand, exposed to great action of solar heat, the regular wind of the desert must be a current upward from its centre, supplied by currents at the surface from all the colder places by which it is surrounded. So far, therefore, are the deserts from being out of that general action on the surface of the earth, of which water in the liquid state is so powerfully and conspicuously an instrument, that they bear a part in that action, and probably a far

more important part than we are aware of. The great zone of deserts which, interrupted by the courses of rivers, and partially by the ridges of mountains, extends from the northern confines of China to the western shores of Africa, and appears partially again in South America, has far more influence upon the climates and productions of the fertile places, than those who have not very carefully considered the subject would suppose. If it were not for the heating of the central desert of Asia, by the action of the summer sun, which brings the south wind loaded with moisture, there would be no rain in India; and India would, in very few years, form part of the desert. So also, if the heated desert of Sahara did not bring the cool and humid wind from the Gulf of Guinea and the country of the Niger on the south, and from the Mediterranean and the mountains of Atlas on the north, the half-parched lands on the margin of the desert would soon become wholly parched; and the desert would spread on every side, destroying the springs and rivers, and putting an end to the growth of vegetables and the subsistence of animals.

Indeed, it is doubtful whether, if it were not for this same desert, the crops in England would come to maturity; and whether our fields would not be ice-bound in winter, and parched and barren in summer. The south-west winds which blow over us, if not always at the surface of the ground, during the greater part of the year, and which bring us the rains of spring and summer, and warmth generally, are put in motion by the trade wind on the Atlantic, and there is no question that the African desert has considerable influence upon that wind.

The northern parts of America, where there is no desert of any magnitude in the same longitudes and on the same side of the equator, have no south-west wind, as we have, to bring showers in the summer, and soften the rigours of the winter's cold. The climate there may be taken as a specimen of what we should have in Europe, if the general currents were suspended, and we were left to our

own local and seasonal distribution of moisture and of heat.

In the southern part of Upper Canada, which is nearly on the same parallel as Italy, the thermometer is 52° below freezing in winter; and at a latitude corresponding with that of the northern parts of Sweden, the winter temperature is 30° lower than that, or 83° below freezing, which is 12° below the freezing point of mercury. The summer temperature in those parts of America is proportionably high, being equal to that of the tropics, that is, several degrees higher than the healthy temperature of the human body; whilst the atmosphere is cloudless, and the marshes of course reeking with vapour.

Though man, with his artificial clothing scientifically adapted to the circumstances in which he is placed, can bear changes of temperature better than any other living creature; yet so great a change can hardly be healthy. The earth, too, feels it; but it suffers from the dry heat of summer, and not from the intense cold of the winter. That cold is in the atmosphere, and as the atmosphere is dry it does not feel disagreeable. The earth is protected by a covering of snow, which prevents it from being cooled much below 32°. Indeed, it is the warmth of the earth which contributes to make the air so cold; for if the air had access to the surface of the ground, it would cool it, and get warmer by the process.

But when the snow melts, the ground is chilled by the vast quantity of snow-water which stagnates on the comparatively flat surface, and soaks into the ground, saturating it with water at the temperature of 32°; and as mud and water freeze far more readily than water when pure, from the particles of mud affording points of commencement to the congelation, the cohesion of the soil is loosened by partial underground freezings. The winter shroud of snow, and the intense drought of the summer, are both unfavourable to grasses; and accordingly, with the exception of a few aquatic species, which resemble reeds more than the fine grasses, the grasses in that

part of America are few. Few herbs of any kind grow in the shade of pine forests, which is more congenial to the smaller mosses and lichens. Accordingly, the soil is of a peaty nature; and, as such, the heat dries it up and renders it unproductive. So difficult indeed is it to keep the land in fertile condition, that, in many parts of the country, lands which have been cleared of timber and under culture for some years, may be had cheaper than those upon which the labour of cutting down the timber has still to be performed.

That there may not be other causes for these differences of climate between the north of America and the north of Europe, than the absence in the former of that general south-west current, which has so beneficial effects in the latter, we do not pretend to affirm; but, at the same time, it is certain that the absence of that current is a great disadvantage to northerly America, as compared with northerly Europe; and that, as the deserts certainly do assist in the production of the current, they are an advantage to all those places which are under its influence.

Section LXXXIV. Without Liquidity there could be but little action.

The circumstances noticed in the preceding Section have been introduced for the purpose of showing to what an extent an apparently simple principle will carry us, when we follow it out with even a very moderate degree of scientific knowledge. In fact, the principles and properties that we meet with in nature (and they are the only ones by which we can be guided in art) are so linked together, that when we enter upon an original examination of one of them, there is no knowing what others may force themselves on our notice, or to what extent they may occupy our attention and influence our conclusions.

This should teach us to be cautious not to despise or find fault with any object or event that we meet with in nature; for that which we, in the sufficiency of our igno-

rance, might pass over or turn away from, may be the very thing which, if we understood it better, would completely answer the purpose we have in view. A person, for instance, who is ignorant of the principles of Geography, and the portion of temperature and moisture necessary for ripening the fruits of the earth to that degree at which they are most profitable and wholesome for man, might be apt to consider the winter of England, with its short days, its rains and fogs, and the consequently uncomfortable state of the fields and pathways, an evil. But so far from this being the case, we could not have the budding spring, the blooming summer, and the abundant harvest, without the winter. The winter is not the cause of the summer; but still all the seasons are so linked together, and their general characters are so dependent on the particular portion of the earth's surface which our island occupies, that we cannot have the one without the other. If our days and nights had been of equal duration throughout the year, there would have been few nights without frost; and therefore no useful vegetable could have come to maturity. In regions nearer to the pole, the state of things would have been worse; so that, if the globe had had what we are in the habit of considering as perpetual spring, more than half the surface of it would have been barren and useless.

Thus the simple fact of the line round which the earth performs its daily motion making an angle of a little more than $66\frac{1}{2}°$ with the plane of the orbit in which it revolves round the sun during the year, instead of an angle of 90°, which would have made the days and nights equal in all latitudes, is so linked with the whole economy of the globe and all its productions, that but for it, all would be confusion and ruin.

It is this obliquity which equalizes the temperature, and gives a hot summer to those places which cannot, in the nature of things, have a hot year, and the distribution, simple as are the means by which it is effected, operates so, that, in proportion as the summer, as a whole, becomes

shorter, the summer nights (those portions when the immediate action of the sun's heat is suspended) are the shortest also.

Thus, the succession of the seasons is the distribution over the globe of that temperature which is most favourable to the liquid state of water, and of the watery juices of plants and animals, without which the beams of the sun would fall in vain upon many of its latitudes. On the other hand, if the cohesions of those substances in which the functions of growth and life are carried on while they are in the liquid state, had not been given to them so adapted, that they are in that state at the average temperature, the seasons would have revolved and the beams of the sun shone in vain. It is in these general adaptations, so very simple yet so perfect, that we see the beauty of creation, as *one work*, and feel, beyond the possibility of doubt, that it is the production of *one CREATOR*, whose power and wisdom have no limit, and who must, ere He spake the universe into being, have known every quality of every thing, and every circumstance of every event.

If there had been no middle state of liquidity between substances obeying the laws of their individual cohesions and the state of vapour, there could have been no action in solids, except action so violent that it would have rendered them invisible. Solids never unite but through the medium of liquidity; and the only action that we can assign to a solid, as part of a system, is that of obeying the law of gravitation—falling down when there is nothing to support it. A creation of solids would thus be a very helpless creation. It would be a creation that could fall down, and lie still when it could fall no farther; but it would be nothing more.

The world around us is full of proofs of this. The shores of the ocean are surrounded, and the shallow parts of its bed are covered with the ruins of the land; the lower valleys are fat with the waste of the upland countries; the skirts of the mountain are made fertile by its sides; and the base of the precipice is cumbered with its

fragments. But not a solid thing moves one hair-breadth upwards of itself, no, not the very lightest grain of dust. Before that can take place there must be heat, or something which heat has loosened from the fetter of gravitation and fitted for motion.

It may be said, that the tendency to fall is much greater in liquids than in solids—that a ball, or even a lump, cannot be formed of any liquid, but that its parts all yield so readily to the law of gravitation, that it always stands with its surface equally distant from the point or centre to which it gravitates. For instance, if a narrow vessel—say only one inch in section—is connected with one ever so wide, by means of a pipe at the bottom of both, water will stand at an equal height in the two vessels. And if an additional pound of water be poured into the narrow one, it will raise as many pounds in the wide as there are inches in its section, until the water again comes to the same height in both.

This is not only true, but, if a tube which admits a liquid to pass freely, be made strong enough, and of sufficient height, and the lower end of it communicate with the under part of a vessel full of the same, or any other liquid, and having no means of escape, a very small quantity of liquid poured into the tube may be made to exert so much pressure as to burst the vessel.

Thus, a pipe an inch in diameter and a mile high contains about 36 cubic feet, or nearly a ton of water, and this water presses on the inch of base with the force of a ton. Now, if such a pipe is supposed to be a perpendicular fissure in a mountain, and to terminate below in a cavern which has no outlet, and which presents towards the weak side of the mountain an extent of thirty yards in length and ten yards in height, the pressure tending to burst the mountain will be very great; namely, 259,200 tons, a pressure which it would take a strong mass of mountain to resist.

But though the pressure of water, arising from its perfect obedience to the law of gravitation, thus acts as a

power in nature, and is also used as a very cheap and efficient power, in art, as in turning wheels by its falls, and wafting vessels along by its currents, all of which are in whole or in part produced by its obedience to gravitation; yet the very same loosening of its cohesion which enables it so perfectly and uniformly to obey this law, makes it obey other laws, to which it offers greater resistance than to that of gravitation when in the solid state.

The descent of a solid by gravitation is a power, to the full extent of its weight, or quantity of matter, the same as the descent of a liquid; but the solid is a dead power; the liquid, in a certain sense, a living one. When the solid has once descended to the bottom of its fall, it lies there, and returns no more to its work, till it be again lifted up; and the labour of raising it, independently of that of bringing it to its place after it is raised, and the friction of the process both ways, is fully equal to all the power that it can exert in its descent.

A descending weight is therefore never used as a first power, except when the regulation of motion and not the force of motion is the result—as in clocks and wind-up jacks for roasting. Hand-hammers, tilt-hammers in forges, stampers in mills, and coining and stamping-presses, never have the force as the original power; and though they concentrate that power, it is always at a loss; and, independently of the power lost in other ways, there is always as much consumed in simply raising the weight, as there is obtained in the descent of it.

With the stream that turns the mill-wheel, and the current or the tide that carries the vessel the case is very different. The stream, though it flows constantly down the slope, finds its way back again, if not in the same identical liquid, yet in liquid which answers the same purpose; and though the tide that brings in one ship upon its flood ebbs away, another tide follows at the stated interval; and though the water may not be the same, and the extent varies according as the attraction of the moon and the sun are exerted in unison or in opposition, the tide re-

turns to do its office, without being raised by any labour of man.

Thus we see that, as the resistance of substances and the action of heat exactly balance each other in the liquid state, that state is the one in which matter is ready prepared as materials in new operations. It is true, that there is not in the liquid itself any tendency to motion in any direction but that of gravitation, unless it be acted upon by some cause from without. Liquids of different specific gravities arrange themselves in the order of these; the heaviest nearest to the centre toward which they gravitate, and the others in their order. Some very neat experiments may be performed in glass vessels, in illustration of this. Thus, if two liquids, of different specific gravities, each of which is tinted by a colouring matter not soluble in the other, or one coloured and the other not, be put into two glass vessels, which communicate by a narrow opening; and if the vessels be so placed that the one with the heavier liquid be uppermost; the ascending current of the rarer and the descending current of the denser, going on in the narrow space at the same time, have a very pleasing effect.

But after the specific gravities are adjusted, the motion ceases; and if the application of heat were uniform, and no further change of state was effected, the whole of the liquids would soon be as completely at rest, as if the whole were solid. Indeed, as liquidity admits of a more general, immediate, and perfect obedience to the law of gravitation, in every kind of matter, than can take place in the solid state, a world of liquids would be sooner reduced to dull uniformity than a world of solids.

SECTION LXXXV. EXPANSION, UNION, AND CAPILLARY ATTRACTION OF LIQUIDS.

As all liquid states are maintained through a considerable range of temperature, that of water from 32° to 212°, or 180°, being about the least; and as they all expand by

heat, and contract by cold, their specific gravities must be continually changing. But at ordinary temperatures, that is, at temperatures not exceeding the highest produced by the direct action of the sun, these changes are very small. Generally speaking, too, those liquids which have the least specific gravity expand the most; and when that is not the case, the difference of expansion (excepting, perhaps, in the case of salt water and fresh water when near the boiling point) is not equal to the difference of specific gravity.

Thus, though the action of heat upon liquids may produce a motion of the parts of the same liquid, by the ascent of that which is heated and the descent of that which is cooled, or a contrary motion in some few cases, as in that of water below 39°; and though there must be slight lateral movements to accommodate the whole altered mass to the centre of gravity, yet no action can be produced by heat on liquids, by means of which one liquid can be made to ascend through another, so that the position of the two with regard to the centre of gravity shall be reversed. Oil stands on the top of cold water, and no heating can bring the water as a liquid to the top. Indeed it is not easy to bring it to the top in any way, if the stratum of oil be thick enough; for then the water does not pass off in steam till considerably above the boiling point. The boiling point of oil is 640°, or 428° higher than that of water; but at the boiling point of water the oil has expanded one-twelfth of its bulk; the water only one-twenty-second part.

It is upon this principle that we are enabled, by the application of heat, to separate from water those lighter substances that expand faster, and also those heavier, or equally heavy substances, which do not expand so fast.

Thus, the unfiltered water of rivers, as that of the Thames at London, usually contains a portion of animal and vegetable matter, which is specifically lighter than water, and also earthy particles, which are specifically heavier, but held suspended, either because they are

agglutinated by the others, or because they are in a state of minute division, and suspended by the capillary attraction of their surfaces for water. But when the water is heated, these unions are dissolved; and the light matters come to the surface in scum, while the heavy fall down in sediment, and leave the body of the water pure.

Water of this description often (indeed generally) contains some sulphuric acid in combination with lime and iron, and alumina (clay), the solution of which is transparent, more especially when the water is cold. If such water is boiled it becomes turbid, and if the boiling be continued for a considerable length of time in iron vessels, the sulphuric acid attacks the vessel, and the iron and clay which it held in solution are precipitated in the state of ochre, which is alumina coloured by a very little iron. This process purifies the water, but it soils the vessel, to which the precipitate adheres, causing what is called 'furring.' This may be prevented, and the water more completely cleared of the impure matters, by putting quick lime (calcined oyster-shells is perhaps the best form of it) into the vessel. The sulphuric acid attacks the lime and partially converts it into plaster (sulphate of lime); and the iron and clay are deposited in ochre upon the surface of the shells, and the vessel is left clean, while the shells are easily replaced. When the water contains carbonate of lime and silica, the incrustations are still more difficult to remove, and they are often found very troublesome in the boilers of steam-engines. The sulphuric acid from the clay attacks the lime in these cases, and the precipitate is a very insoluble compound of plaster and ochre. So strong is the tendency of sulphuric acid to combine with lime in boiling water, that if a common figure of plaster of Paris is boiled in alum water, it takes the acid out of the alum, acquires a hard surface, which polishes like alabaster; and the clay, usually combined with a little iron, is found in an impalpable powder at the bottom, or in the hollows of the figure. If the figure be cast in one piece, it may be much improved by this mode of treatment; but if there be

joinings in it, these are very apt to separate by the water soaking into them.

When liquids mix readily, that is, when they have an attraction for each other, and pass into one uniform liquid, there is generally a condensation, and a disengagement of sensible heat. This is the case to a slight degree when alcohol is mixed with water; and it is violent almost to ebullition when strong sulphuric acid and water are united. By an application of the first of these, the people of some places avoid or mitigate the danger that results from drinking cold water when the body is warm. The danger consists in the sudden cooling of the heated throat and stomach by the cold water, which by the contraction that it occasions, may check the circulation, rupture some of the minute vessels, and suddenly bring on inflammation.

The heat which is felt after violent exercise is the consequence, not the cause of thirst; so that the old name 'drought' is an expressive one. The exertion heats the body; the evaporation increases, and the moisture is lessened. As long as the moisture is in sufficient quantity, the evaporation of it takes away the heat, and no inconvenience is felt; but when it is carried to excess, either by its severity or its long continuance, we literally become dry. If a very small quantity of ardent spirit be taken, and then the draught of water, the heat evolved by their union takes off the chill, which either the one or the other, or the two mixed previous to swallowing, would augment. In fact, though we are accustomed to say that ardent spirit is *hot*, the effect of it is exactly the reverse; it evaporates sooner than water, and thus it actually injures by cold, by chilling the internal surface and producing inflammation; and if it be often repeated, it causes the same deadening effect upon the internal surfaces, that alternate exposure to the fire and the frost produces on the hands.

On the contrary, when any two liquids unite with difficulty, there is no diminution of bulk, and no sensible

production of heat; and however intimately such liquids may be mixed by mechanical means, they separate by their specific gravities much sooner than the others. As they separate by their specific gravities, they must also separate by means of heat, which enables those gravities to act more promptly.

But liquids which have an attraction for each other, and give out heat, when they are mixed at the same temperature, enter more intimately into union by increase of temperature, unless the degree of heat be so great as to separate one of them in the state of vapour. It is the same with two bodies that have an attraction, even though at the time of their union one of them should be solid, and the melting of that during the process of uniting should produce ever so great a degree of sensible cold.

It is upon the principle of these attractions that the action of what are called 'frigorific mixtures,' or 'freezing mixtures,' depends. Thus, when two parts of snow, or pounded ice, are mixed with one part of salt, the tendency of the two to unite is so great, that the crystallization of both is instantly destroyed, and a degree of cold, equal to — 5°, or 37° below freezing, is produced. Snow three parts, and muriate (hydrochlorate) of lime four parts, reduce the temperature from 20° to — 48°, or 68°, so that a portion of mercury exposed to the mixture would become solid. Liquid water and sulphuric acid, when united, produce a very considerable degree of sensible heat; but four parts of snow, and five of the diluted acid, when previously cooled to — 48°, produce by their union the intense cold of — 91°, which is 123° below freezing,—a degree of cold at which any metallic substance would produce the same sensation, and nearly the same effect, on the human body as a live coal. In fact, we must deal with iron, which is hammered red hot, and mercury, which solidifies at 39°, and may be hammered at all lower temperatures, nearly in the same manner,—we must hold them with tongs, or in both cases we shall 'burn' our fingers.

The attraction between two bodies may be discovered when one of them is liquid and the other solid, even when the solid has no tendency to melt. The liquid, in these instances, wets the solid; and the wetting may take place, though the attraction is between the liquid and only one of the parts of the solid. Thus, water wets glass, though the alkaline flux of the glass is the substance between which and it the strongest attraction exists. Water has little or no attraction for resins and essential oils, such as rosin and turpentine, but it has an attraction for gums. Hence pine timber, when it contains much turpentine (the turpentine in the wood is the oil and resin mixed), resists the action of water, which speedily rots the wood of gummy trees, such as cherries and plums.

Liquids that wet the surfaces of solids, rise in the openings of them by what is called *capillary attraction*, if the gravity of the quantity of liquid in the opening, and the downward pressure of the weight of the atmosphere, are not too great for being overcome by the attraction.

This species or modification of attraction is called capillary from the Latin *capillaris*, 'like a hair;' because it is best seen by the ascent of a coloured liquid in a glass tube, the bore of which is slender like a hair. But it also takes place between flat surfaces of any extent, if they are near to each other, and the edges of both in the liquid.

If a small quantity of liquid which has the wetting property, or capillary attraction, be put between two plates of solid, which are closer at one end than at the other, it will move towards the close end, while one not having that property will move toward the open end. Water and mercury between two plates of glass are instances. If water is coloured, and two pieces of glass are set on their edges in it, touching at one end, and opened a little apart at the other, the water will rise at the close end, and less and less as the other is approached. The heights will be inversely as the squares of the distances of the plates; and

thus, the outline of the water at top will be a hyperbola, —the figure which, if the air were perfectly still, smoke or vapour would, if we could see it, assume as it rises and spreads in the atmosphere.

Spongy substances suck up water upon the same principle; and so do many species of stone—porous stones obviously, and also many of the clay-stones which appear perfectly solid. The case is the same with the pottery which is baked at a low heat, and with badly burnt bricks. When substances have an attraction for oil, it rises in them in a similar manner, as in the wicks of lamps.

But capillary attraction does not produce a current *through* the tube, even under the most favourable circumstances, unless it is assisted by gravitation. Thus, though a porous vessel may empty itself by the bottom or through the sides under the surface of the liquid, it will not, without the aid of evaporation, empty itself over the top. A basin of water may be emptied by a moist skein of soft cotton; but then the end by which it is emptied must hang over the side of the basin, so that the quantity of water in the thread outside the lip is heavier, that is, forms a longer column than the quantity above the surface of the water inside.

Capillary attraction produces many curious phenomena; but we must not fall into an error with regard to it, and we are always in danger of doing so when we study a curious principle minutely and exclusively. We must be careful not to impute to it effects which it cannot, in the nature of things, produce.

Now, as capillary attraction acts only between surface and surface, it cannot act farther than those surfaces extend; and as, when it acts upwards, it acts contrary to gravitation, and overcomes, but does not destroy, the tendency in the liquid to gravitate, it must then act at some disadvantage—not quite so fully or so freely as when gravitation operates in concert with it. Thus, whatever effect capillary attraction may have in raising moisture

within the earth as high as the surface, it never can make that moisture flow out in a spring, or rise in a jet. These must always be produced by hydrostatical pressure, either the pressure of a 'head' of water above the orifice, or the pressure of strata heavier than water upon the yielding stratum in which the water is contained.

Examples of the latter are seen in ice. If there are small holes bored quite through, and a number of persons come on the ice, the water will spout up in a jet. So also when a 'spring head' is gradually compressed by the expansion of ice forming more and more closely upon the water, it bursts into a hump in the middle; and if the frost is of sufficient intensity and duration, it may rise to a considerable height. The 'hummocks,' which rise above the rest of the *glaciers*, or ice fields, in alpine countries, are produced in a similar manner.

Those who have wished to make more of the principle of capillary attraction than can fairly be attributed to it, have sometimes said that it is the cause of the budding of plants, and the elongation of the stems and twigs. This, however, is a mistake. If it were true, pendant branches would elongate more than upright ones, because then the attraction of gravitation would help, or at least not hinder, the capillary attraction. In fact, an upright stem could not elongate at all, because there is nothing beyond the already formed part, between which and the sap of the plant capillary attraction could act.

Whether the tendency to elongate be vertical, horizontal, or drooping, depends on the habit of the vegetable, and not on any general law, such as that of capillary attraction; and, therefore, we are warranted to conclude, indeed we cannot help concluding, that there is in every species of plant a determinate principle of growth, just as there is in every crystallizable substance a determinate mode of crystallization; and that each belongs specifically to the plant and the crystal, without any reference to the general fact of their all being matter.

This consideration ought to guide us in all our attempts

at generalizing. To generalize scientifically is to trace similarities which we actually observe. To infer that which we have not observed, is error—error from which it is exceedingly difficult to return again to the plain path of truth and nature.

Section LXXXVI.—Bodies in the Aerial or Gaseous State.

Though the actions which take place in and among liquids, and between liquids and solids, are, in many instances, very interesting, and very necessary to be known, in order that we may understand the phenomena and properties of natural substances, either for the purposes of general science, or for the application of the principles of that science to the arts of life; yet they are very limited in their individual extent. So that, if there were no other means of extending and communicating action but those that take place among solids and liquids, the operations of nature would be few in number, unimportant in effect, and soon at an end.

The solid and liquid states have their importance; the one in giving stability to the productions of nature, and the other in allowing a certain range of operations to take place; but still the only powers which are in them (if powers they can be called) are those of gravitation and cohesion. By the first of these they all tend to the common centre of gravity—the centre of the earth for all things which belong to it; and by the second, the parts of each individual body tend toward one another. So that these are what may be called *neutral powers*, which keep substances in their places, and preserve their individual existences; for, in consequence of them, no substance acts upon another, in any way but by pressing it by weight.

It is true there are the attractions of different substances for each other—those attractions which are sometimes called *affinities;* because, in some instances, such as

that of the snow and salt, each of the substances, as it were, forsakes the law of its own crystallization, and the temperature at which, singly, it would melt, in order to combine with the other.

But before bodies can display these attractions of affinity, they must be brought together. The salt, of which there are such extensive beds in the eastern slopes of the Alps, never approaches the central mountains of that ridge to unite with the snow which lies permanently there, and even, if the snow and the salt are but one inch asunder, they have no action upon each other. It is the same with all the attractions of affinity, whether they take place between solids or between liquids. They do produce unions; but these are the results of juxtaposition, or proximity; and, as the attraction is only between atom and atom, it has no tendency to move the smallest portion of matter which we can call a mass, through even the smallest measurable distance, until the action of one upon the other has been not only begun, but carried on to a considerable extent.

The principles are, no doubt, in the substances, and that it possesses those principles is the only means which we have of knowing the substance; but the two substances must be brought together.

The aëriform or gaseous state of a body is that state in which the attractions of its particles for each other are so overcome by the action of heat, that they can, to our perception, undergo no further change of state. In the state of air, bodies, generally speaking, are transparent, and invisible. Their weight is not altered, though they are greatly increased in bulk, and their specific gravity is diminished in consequence. Their cohesion is not only so far destroyed that they cannot keep their shape even in drops like liquids, but their particles absolutely repel each other, so that a body in the state of air will diffuse itself through any space, however large; and, except so far as gravitation is concerned, it will diffuse itself through that space equally.

Up to a certain point, airs or gases yield easily to compression; and as they are compressed they give out heat. When the pressure is removed they return to their former bulk, if as many degrees of heat be communicated to them as they gave out on compression; but if less is communicated, the bulk to which they return is less; and if more is communicated, the bulk to which they extend is greater. The readiness with which a body yields to a force compressing it, and returns to its former state when that force is withdrawn, is called the degree of its *elasticity*.

Gases are sometimes called *elastic fluids*, and liquids *non-elastic fluids;* but the terms are not applicable. We are in the same condition of ignorance with elasticity as we are with heat, and all the other appearances and changes of appearance that we observe in matter; we know nothing about the beginning or the end of it—the smallest degree or the greatest. We know a certain range, and within that range we can compare the appearance in one body with that in another, or we can compare the variations in the same body, by referring them to some other body as a standard; but beyond that range we know nothing; and if we imagine that we do, we deceive ourselves.

So little, indeed, do we know about the intimate nature of bodies, that we are not certain but every change of state, both in temperature and in bulk, may be the action of two different substances upon each other. This may be the case in those bodies which we consider as simple, just as readily and reasonably as in those which we know to be compound. Our distinction of compound and simple is not a distinction in nature, it is merely the distinction between what we know and what we do not know.

Sixty years barely have elapsed since it was proved, by the composition of it from its component gases, oxygen and hydrogen, that water is a compound substance; and

neither of those component elements of water has yet been obtained separately from other substances, either liquid or solid, but only in the state of air. When they combine and form water, the operation is attended with the most intense heat, and therefore we may regard it as one of the most energetic actions with which we are acquainted. It is not at all unlikely that the giving out of heat in freezing is the result of a closer, and the absorption of heat in thawing the result of a looser, action and union between these gases. So also, in the more powerful heat which is given out when the vapour of water is condensed, and the greater absorption when liquid water is turned into vapour; it may be produced by the increasing action of the two substances upon each other in the one case, and their diminishing action in the other.

There are many effects resembling these, produced in cases where there is nothing that we would, in common language, call a source of heat. When the savage wishes to kindle a fire, he rubs one dry stick against another till one of them kindles. The blacksmith hammers a cold rod of iron on the cold anvil; and without abstracting heat from the anvil, the hammer, or his own body, (for all three may become hot,) he brings the iron to a red heat and lights his forge-fire. By striking a cold flint rapidly against cold steel, portions of the latter are thrown off in a state of absolute combustion; though to effect the same on a larger scale requires the white heat of the forge. When ice strikes ice, or air strikes air, with very great force, fire is produced. These and many other cases, with which everybody is familiar, should warn us not to speak too positively about the kind of action by which bodies are brought to any particular state; and then we can, without prejudice, and therefore with profit, examine the appearances, which is all that we can really know on the subject.

Section LXXXVII. Process of Evaporation.

We have no good general name for the change of bodies to the gaseous state. Evaporation is perhaps the nearest; bnt *vapour* is not exactly gas, it is rather a liquid diffused through a gas in very minute portions, and sustained there by some agency, analogous perhaps to capillary attraction. Substances are understood to pass into vapour at much lower temperatures than they change into gases. Thus, water passes into vapour even when in the state of ice; but, other circumstances being the same, the higher the temperature is, the more rapid is the evaporation. When, however, the process itself is understood, the name that it is called by is of minor importance.

The substance which is most convenient to take in illustration, is water; and, at ordinary temperatures, and by ordinary means of applying it, water is turned into vapour, and not into its component gases. The separation of these can be obtained only by the combination of one of them with another substance; and the two together only by a double decomposition, in which one part of the water is deprived of the one, and another part of the other. This can be brought about only by an action equally powerful, or indeed more powerful than that with which they combine, and therefore the consideration of it belongs properly to another branch of natural science. Hence, we shall confine our present observations to the production of *steam*, which is the vapour of water produced at the boiling point, namely 212°, or 180° above freezing.

Up to 212° water gets warmer by the application of heat; the air which is contained in it escapes, and common evaporation goes on increasingly as the temperature rises. But when 212° has been reached, if exposed to the air, and under the mean pressure of the atmosphere, the thermometer shews no more increase of heat; but the water passes off in a cloud, if permitted to escape in the

open air, where it speedily cools and condenses, but in invisible vapour, if in close vessels, by means of which the heat can be kept up.

In a philosophical sense, steam is both dry and transparent. When it assumes a cloudy appearance, as when issuing from the spout of a tea-kettle, or the safety-valve of a steam-engine, it is partially condensed, the air with which it mixes being at a lower temperature than itself. And this distinction is equally applicable to steam, or vapour, at all temperatures; whether it be that resulting from a natural process, and which is called *spontaneous evaporation*, or from the application of heat by artificial means, which is designated *vaporization*. In familiar language the use of the term *steam* is limited to the latter process.

The action of the specific or latent heat in separating the particles, not of the oxygen and the hydrogen, for this takes a heat immensely greater, but of the compound water, is now greatly increased. The volume is augmented about 1700 times in bulk, or one cubic inch of water becomes very nearly a cubic foot of steam. The specific heat is then equal to about 1000° of Fahrenheit; but the temperature is only 212°. In this state the steam just balances the pressure of the atmosphere. The specific gravity of the steam is, of course, inversely as to its expansion, or $\frac{1}{1700}$ that of water. The specific gravity of atmospheric air at the mean temperature (60°) and pressure (30 in.) is about $\frac{1}{840}$ of water. The specific gravity of steam at 212° to that of air at 60° is nearly as 10 to 22. If free to expand, the steam does not become sensibly hotter; on the contrary, by the separation of its particles its heat is rapidly dispersed, and it returns again to the liquid state.

When confined, the elastic force of steam increases very rapidly; and if the heat is produced in a boiler in which there is more steam generating, there are two causes that augment its force—first, the direct heat upon the steam already generated; and secondly, the con-

densation and increase of density, and consequently of tendency to expand, occasioned by the steam which is added.

It is not very easy to divide the resulting expansive force properly between these causes; but the general mode of action may be readily understood. Suppose that the space in which the whole steam and water are contained is four cubic feet, and that three of these are filled with water. There is one cubic foot for the steam, and one inch of the water fills it to the pressure of one atmosphere. But if it has no means of escape, it must, after the evaporation of every additional cubic inch of water, have its density nearly doubled, the inch of room being the only difference. If we could suppose the vessel strong enough to resist the expansive force till the whole of the water were converted into steam, the steam of three cubic feet would be contained in the same space which, at 212°, would exactly hold that of four inches. As the steam would in this case occupy only one-fourth more space than the water, it must have three-fourths of the specific gravity of water, or 615 times that of air. This would give a pressure of between 3000 and 4000 atmospheres, or twenty-five tons on the square inch, the fourth of which would suffice to crush granite to atoms; and as there is no reason why the water might not have borne a much higher proportion to the empty space, there is really no assignable limit to the expansive force of steam; and, therefore, no resistance which it is not capable of overcoming.

These, too, are the effects of mere vapour, and not of the resolution of the water into its constituent gases. That, as we have said, demands an action yet more powerful; an action which is of necessity commensurate with what takes place when those gases are again united into water. In that heat, even upon the small scale on which we can produce it by our little experiments, (and these are, of course, as nothing compared with the operations of Nature, in which the pressures are oceans and mountains,

and the strength of a globe, thousands of miles in diameter, is the medium of resistance,) the most stubborn substances yield, as dry wood to the fire, as wax to the seal, or as the air to the passage of the lightning.

A condition consequent on the application of heat to liquids, and dependent, probably, on the form of their particles, demands here a passing observation. Some of the phenomena to which we shall allude were undoubtedly witnessed at a remote period; but it is only very recently that they have been sufficiently noticed as to become special objects of scientific investigation.

When a few drops of water are thrown upon a heated surface, say, of metal, almost or quite at a red heat, the water does not diffuse itself and wet the metal, and then pass off in vapour; but it comports itself in a manner totally different from what happens at ordinary temperatures. Assuming the form of globules, it rapidly rolls about, without appearing to be in actual contact with the metal, whilst the process of vaporization goes on so slowly that it is scarcely perceptible. Let us examine this a little more closely. It may assist us in understanding things which have hitherto been hastily passed over without even an attempt to explain them philosophically.

The fact just related must be taken as a starting-point. One example will be sufficient as a further illustration.

If we provide a small plate of silver made slightly concave, and perfectly clean, and place on it a few drops of water, at the ordinary temperature, the surface of the metal will be moistened by the liquid at the points of contact. Apply heat to the plate, say, by means of a spirit-lamp, and when the water attains the temperature of 212° it enters into ebullition and soon evaporates. Raise the temperature of the plate nearly to redness, and project on it the same quantity of water as before. There will neither be ebullition nor sensible vaporization. Everything has changed. The water suddenly separates into spheres, or rather oblate spheroids, which roll about

at a certain distance from each other; and although we continue to apply heat to the plate, the temperature of the water, at the moment it assumes the spheroidal state, will fall below 212°; and so will it continue as long as that of the plate remains above it. Here we have an instance of water refusing to boil when heated above its ordinary boiling temperature; and not only so, but the vaporization of the globules of water goes on so slowly, that it is estimated to be only one-fiftieth of its rate under ordinary circumstances. Thus are we taught not to be too hasty in our conclusions as to what we know about the laws which control natural processes. Some of these laws are known to us, but only a small part. Accustomed to view them as associated only with one set of conditions, we may have to modify our operations to make them conform to other conditions. In the ebullition and vaporization of water and other liquids, there is probably more yet to be discovered; and every additional exemplification of these phenomena, we may be well assured, will be for the benefit of the whole world.

The spheroidal form which the water, under the circumstances just described, assumes, and the entire change in its habits as to boiling and vaporizing, are probably due to a film, or atmosphere, of highly attenuated vapour, in which each spheroid is enveloped. Contact with the surface of the metal is thus prevented; and as it is well known that vaporization generates large quantities of electricity, it is not unreasonable to suppose that the separation of the water into distinct globules, their assumption of the form indicated, and their rapid whirling motion, might be occasioned by electrical action operating much in the same manner as upon pith-balls, which jump about under an electrically-excited glass tumbler.

Whatever be the cause of these wonderful deviations, from what is familiar to us in common processes, the effects are very instructive. Many things which once appeared incredible, and, although well attested, always

awakened suspicion, are now divested of the marvellous. Walking on red-hot iron, applying it to various parts of the body, dipping the hands into lead, or copper, in a state of fusion, putting live-coals into the mouth, and emitting smoke and sparks from the mouth and nostrils; are some of the tests associated with ordeal by fire in the dark ages, the feats of professed mountebanks and jugglers, and the exploits of workmen by way of bravado, or for a trifling fee. Now that we are informed of the spheroidal state of water at high temperatures, and how perfectly it resists heat, we can easily account for what before seemed impossible. It has lately been shown that if the hand be slightly moistened with water, it may be plunged into iron, in a state of fusion, without injury or even inconvenience. It requires courage and self-possession on the part of the operator; and not one man in a thousand would be likely to attempt it, although he may see it done by another. There must be no hesitation. The hotter the metal the better. The only real danger would be in waiting a moment too long, until it began to lose perfect fluidity.

On the principle thus briefly explained, it is easy to account for the explosive force of steam, and the suddenness and extent of the accidents by the bursting of boilers and other kinds of apparatus. These have sometimes occurred under circumstances which seemed otherwise to be utterly incomprehensible.

Section LXXXVIII.—Natural Composition and Decomposition of Water.

When we speak of any operation as natural, the common understanding is that it is carried on in the atmosphere—in the free air, without any other restraint than what arises from its resistance. Of such operations, perhaps the most general, as well as the most important, are the composition and the decomposition of water. The liquid itself is very abundant on the surface of the earth; it is

diffused in vapour every where through the atmosphere; it enters into the composition of all plants and all animals; there are very few crystals of which it does not form a part; and the earths themselves are *hydrates*, or compounds of metals with hydrogen.

Potash and soda, the first of which is found so abundantly in land vegetables and in the composition of rocks and soils, and the second in the waters and productions of the sea, and also in abundant strata in the earth, are also hydrates, in what used to be considered their pure state.

The metals which constitute the base of these substances and hydrogen have such strong attractions for each other that they combine whenever the metal comes in contact with water; and the combination, like that of oxygen and hydrogen in the formation of water, is accompanied by great heat. But though the union is formed thus readily and actively, and is obviously attended by the withdrawal of that action of heat by which hydrogen is kept in the state of liquidity which it has in water, yet no ordinary heat that we can apply can again separate the compound.

We have already noticed the vast, the absolutely immeasurable force with which oxygen and hydrogen adhere to each other in steam; and we may safely say that we might as soon attempt to cleave the globe by mechanical force, or melt it by a fire kindled on the surface, as to separate by either of those means the oxygen and hydrogen of a single drop of water.

But that which we cannot accomplish by the direct action of the most powerful means that we can use, is constantly going on in nature in countless thousands of ways; sometimes with displays of light and heat proportionate to the intensity of the action, sometimes with heat without light, and sometimes when neither is perceptible.

The metals which we have referred to as being the bases of the earths and the alkalis, are hydrates; and

they separate the hydrogen from the oxygen with great violence; of course, by means of a greater power than that by which it is combined with the oxygen in water. The compounds so formed are exceedingly stubborn, so much so that instead of decomposing, our furnaces cannot change the state of the earths even to liquidity, without the assistance of other substances. The substances necessary for this purpose are those very hydrates themselves, as in the cases of glass and the vitrifiable ingredient of porcelain. The flint of glass is the hydrate of *silicum*, and the soda the hydrate of *sodium;* so that it is the joint action of the two metals upon hydrogen, when the mechanical adhesion of the substances is sufficiently loosened by heat (for that is the whole effect of the furnace), which operates in the making of frit, or rough glass, out of the materials. Lime partially answers the same purposes; and, as is proved in the case of lead and manganese, which are added to particular kinds of glass, a metal can be made to answer the same purpose as the alkaline hydrate. Generally, it appears that the effect of hydrogen in compounds is to produce uniformity of internal structure, and consequent glassiness and transparency. But there are so many points upon which we are still in utter ignorance, that the utmost caution is necessary in coming to any general conclusion on the subject.

Oxygen, the other component part of water, is equally active, and equally disposed to enter into combinations with other substances; and as oxygen is one of the component parts of atmospheric air, as well as of water, the sphere of its action is thereby greatly extended. But although hydrogen is not one of the elements of the atmosphere, its specific gravity is so small, being only about one-fifteenth of that of atmospheric air, that when in an uncompounded state, it must ascend into the very highest regions. We know that it does so, for hydrogen is the substance with which balloons are filled. A cubic foot of atmospheric air, at the mean height to which balloons ascend, weighs about fifteen drachms, and a cubic

foot of hydrogen about one drachm; so that every sixteen cubic feet of hydrogen in a balloon will buoy up fourteen ounces of other matter. At the mean surface of the earth, indeed, the weight of a cubic foot of air is about twenty drachms, so that the buoyancy there is much more considerable; and as the specific action of heat, in holding hydrogen as a gas, is twelve times as great as that of atmospheric air, if the hydrogen had room to expand, the difference of specific gravity would become greater and the balloon more buoyant as the height increased. But the balloon must be distended to a considerable degree before it will ascend at all; and when it rises high, part of the hydrogen must be let escape, otherwise it would burst the balloon by its expansion—or if the materials of which the balloon was made were sufficiently strong to resist the expansion of the gas, on permitting any part to escape, it would probably combine with oxygen so rapidly as to set the balloon an fire.

As oxygen and hydrogen do not combine and form water by the process of combustion, unless they are exposed in the first instance to a heat equal to that which appears red in day-light, and which is estimated at about 1000° of Fahrenheit, it may be asked whence this heat can come to the balloon in the upper regions of the air, which are colder than those lower down, and always below the temperature at which water freezes at less elevations than those to which balloons have often ascended.

The answer to this is very simple. The heat that becomes sensible is always in proportion to some resistance of motion; and in the case of gases, in which the attraction of cohesion may be regarded as having ceased to be at all a resisting force, the heat is in proportion to the resistance of expansion. Heat is imparted in the evaporation of water, by boiling or otherwise, which always takes place at a lower temperature when the pressure of the air is lessened. If a gas has freedom to expand (and we know of no rarer *state* into which it can pass), it cannot be sensibly heated. On the other hand, if it be *made* to expand,

there is hardly any limit to the degree of sensible cold that it may produce; but if confined, it may be made to exhibit any temperature whatever. Thus, if the hydrogen in the balloon were confined within half the space that it would naturally occupy in consequence of the diminished pressure of the air, it must show as sensible heat that degree of the action of heat, which, if permitted to operate freely on it, would have doubled its volume. Light as hydrogen is, even at common temperatures, it may be so confined, either by direct pressure against its substance, or by the resistance of its expansion, as that it would ignite the most stubborn body that is known.

Not only does hydrogen rise, in its uncombined state, by its smaller specific gravity, and its greater tendency to expand, but it also rises in vapour combined with oxygen, and with some other substances. Thus there are always the elements of water present in the atmosphere; and could we fully understand their action, we should be able to explain very many of the phenomena that are seen there, whether they appear in simple motion, as wind; in condensation of vapours, as in clouds; in streamy light, as in the aurora borealis; in shooting light, as in fireballs and other meteors; or accompanied by the violent action of heat, and the loud sound of the collision of one portion of air, against another, as in lightning and thunder. Whenever sensible heat is produced, we may be assured that there is a proportional resistance offered to some kind of action; and when cold ensues, we may be equally certain that some resistance to action has given way. Thus, the discharge of electricity which flashes from cloud to cloud, or from the cloud to the earth, in lightning, is probably accompanied by the union of oxygen and hydrogen, and the formation of water; whilst the cold which forms into drops the water already present, or congeals it into hail, is produced by the sudden expansion of the nitrogen after the heat has passed. The sound of the thunder is, probably, the clash of the returning air to that space which had been

rarified almost to a vacuum, by the intense but momentary heat.

We can in this way understand, too, why the shower of rain, and especially that of hail, which accompanies the thunder-storm, should make the air warmer than before. The water which forms these must previously be sustained in the atmosphere by the action of heat, whether it exist as the vapour of water in a state of minute division, or as the separate gases, oxygen and hydrogen; so that when it is sent down as rain, the difference of its former heat above liquid water at the temperature of the rain, must be communicated to the atmosphere; or, if it fall in hail, all its previous temperature above freezing must be so communicated. In the case of the actual production of water by combustion of oxygen and hydrogen, the heat communicated to the air must be much greater. The specific heat of oxygen and hydrogen, which they must communicate to the atmosphere when they form water in it, is so much greater than that of water, and that of water is again so much greater than that of ice, that when no portion of it is sent down by the lightning striking any part of the earth, it is sufficient to raise the temperature of the atmosphere considerably.

Indeed, if it were not for the rapidity with which the air disperses heat, laterally and upwards, in the latter of which cases it disappears in consequence of the expansion, the heat produced by a thunder-storm would be very sensibly felt.

But the extreme mobility of the atmosphere makes it instantly adjust itself to the force of gravitation; the temporary vacuum is closed with the crash of the thunder, arising from the motion of the whole mass of the surrounding air; and the collision is of course great, and the noise loud, in proportion to the extent of the previous exhaustion. The distance to which the driving away of the air by the heat, and the re-action by which it returns, may extend, depends, of course, on the quickness of the explosion, and the degree of heat produced; but air is so

elastic, that it probably extends only a little way. The 'wind of a bullet,' that is, the compression of the air by a cannon-shot in its flight, will stun a person near whom it passes; but it is quite harmless at the distance of a few yards. We see the same limited action in the small breadth over which a whirlwind extends, even when its pressure outwards is so great as to produce a vacuum in which bushes and dust will rise on the land, or water-spouts on the sea.

Section LXXXIX. Combustion and Flame.

Combustion is the general name for the fact of the appearance of light and heat, when substances are forming chemical combinations. When bodies combine at low temperatures, less than that at which light appears, there is not said to be any combustion, though there may be an intimate union; and the result may appear to be one substance. Thus, when sulphuric acid mixes with water, there is no combustion, but there is heat; and there is neither combustion nor heat when oxygen and nitrogen unite in the proportions in which they form atmospheric air. It often happens, however, that a combination, which in itself is not attended with combustion, may, under certain circumstances, bring on another combination, which has that result. Thus, the fermentation which takes place when wet vegetable matters are piled closely together is not in itself attended by combustion; but the confinement of the gases that are generated may be such, that actual combustion with light, and even with flame, may and does often follow.

We are not to understand, therefore, that combustion is an action differing from every other action in kind; it is merely an appearance attendant upon a certain degree of intensity in chemical action; and whenever that degree occurs, it appears, whatever may be the acting substances. When the substances that are combining occupy more space than they did when separate, there is diminished action in that space, and action from the surrounding space is transferred to it, which produces a diminution of temperature

In every case where combination is attended with diminution of bulk, a corresponding degree of heat becomes sensible, or is transferred from the compound to the surrounding objects; but unless both the substances which unite, or one of them at least, undergo a change of state, from gas to liquid, or from liquid to solid, the degree of heat given out is seldom such as to occasion combustion.

Thus, when sulphur and hydrogen combine, which they do in equal volumes, to form sulphuretted hydrogen—the very offensive gas which is so abundant in places where animal and vegetable substances are in a state of putrefaction—the resulting compound has only about five-sevenths of the bulk of the two component gases when separate. The production of sulphuretted hydrogen is, therefore, always accompanied by heat, which further promotes the putrefactive process.

So also, when carbon and oxygen unite to form carbonic acid, the compound occupies only half the space which was occupied by the two component parts, and, therefore, the heat given out is in proportion to the rapidity of the combination, and much greater than in the former instance. But the intensity of the action is, of course, inversely as the time in which it is performed, or in proportion as it is slower, it is less energetic; consequently in some instances of the union of carbon with oxygen, the heat produced is not great.

When grain is converted into malt, when seeds germinate, and when liquors undergo the process of fermentation, there is a production of carbonic acid; but it is slow, and the increase of temperature is, in consequence, moderate. In the action of living vegetables, too, carbonic acid is produced, but it is produced very slowly, and thus, though there is a little heat, it is, under ordinary circumstances, barely perceptible.

The respiration of animals affords still more convincing proofs of the influence which the rate at which the combination goes on has in the production, or rendering sensible, of heat. The cold-blooded animals, such as those

that respire water, or the reptiles that respire air, do it very slowly, and their breathing does not sensibly heat a confined place for a considerable time; while much smaller animals, with warm blood, that respire faster, heat confined air much sooner. A bee-hive is much warmer than a snake's hole, even if there is much more vacant room in it; and one mouse will heat the air under an inverted glass, till it be dewed with water, as the windows of a crowded apartment are on a cold night, sooner than a dozen frogs.

We have very convincing instances in the corresponding variations of our temperature and breathing. When we breathe fast, whether from exertion or from disease, we become warm in the same ratio; and when we breathe slow, we become cold. It it true that our pulse, or the circulation of the blood, is rapid when we are warm, and slow when we are cold; but though they are not simultaneous in the individual acts, yet there is a general connexion between the rate of the circulation and breathing. Indeed there must be; for the blood is not fit for going a second time through the circulation, and, in fact, cannot go through it, till it has been exposed to the action of the air in the lungs.

In combustion the process is often very complex, in consequence of several decompositions and compositions going on at the same time. It is not, therefore, easy to class substances accurately as supporters of combustion and combustibles. In the ordinary acceptation of these terms, a supporter of combustion means a body without which combustion cannot be carried on, and a combustible, a body which is decomposed or burnt in the process. For instance, in the case of a common fire, the oxygen of the atmosphere is called the supporter of the combustion, and the coal, the wood, or the charcoal, the combustible.

If the fuel is charcoal, or charcoal mixed only with metallic substances, the functions, if not the names, are rightly expressed. Charcoal combining with oxygen at a sufficient temperature, forms a compound of these two, and

nothing else; but still, at common temperatures, charcoal resists the action of oxygen and of all other agents better than almost any other substance. There must, therefore, be some process anterior to that combination of the two which forms the carbonic acid. This process is the real source of the combustion, and the continuation of it is the true supporter. The process is bringing the carbon to that degree of heat, at which its own aggregation is so much loosened that it will combine with oxygen; and that is very nearly, if not exactly, the temperature at which it would pass into the gaseous state if the oxygen were not there. In short, the fire must be kindled, and the spark which kindles it must come from somewhere else.

If the spark is originally obtained by a little bit of steel struck off by the rapid and sharp blow of a flint, it is the result of a combination of iron with oxygen; but it is the heat produced by the blow which begins the process. Just so in the case of the fire. The burning match which is applied converts a portion of the carbon into gas, which gas abstracts the heat of the match. The gas so formed enters into combination with an equal bulk of oxygen, and the heat is given out and again acts on more carbon. There is more of the carbon heated than is turned into gas by the match, and there is more and more heated every time, so that the quantity of dissolved carbon increases and the fire spreads. If, however, there were nothing but a simple brimstone match and carbon, whether that carbon were coke from coal, charcoal from wood, or lamp black from the partial combustion of turpentine or any other oil, there would be some labour in getting a fire. The blue flame of the sulphur would play long enough round the charcoal before it would ignite it; and even common coal, which contains something much more easily set on fire than carbon, cannot be kindled without a few billets of wood, or the red-hot poker, or something to begin the process.

Besides carbon, wood contains hydrogen and oxygen; and it is because of these that it goes more readily into

combustion than charcoal. Indeed, it is in consequence of the more easy combustion of the other substances with which it is combined that charcoal is obtained; for they are burnt away, and it is left in the process of charcoal-making.

Yet even the wood requires to have its ignition begun by artificial heat. The carbon is converted into gas at the same temperature as in the other case, and the hydrogen at a much lower temperature; and when these are in the act of forming, they unite in equal measures into half the bulk of carburetted hydrogen which the two occupy apart; and this compound is exceedingly inflammable, so much so, that it enters into combination with the oxygen of the wood, as well as with that of the atmosphere. The hydrogen retains its expansive tendency, and therefore, even while the carbon is combining with oxygen, and forming carbonic acid, and part of the hydrogen with oxygen, and forming a small portion of water, it rises and forms the flame.

Even in very dry fuel there is some water ready formed; and there are in natural products, such as wood and coal, a number of ingredients, and these form a number of combinations, of which a full enumeration would need a very long detail,—a detail which can be followed out only in the study of chemistry as a separate science—a science which every one who can at all command the means of knowing should know.

In all common cases we may lay it down as a general principle, that when combustion is accompanied by flame there is hydrogen in the case; and that the most intense heat that we can obtain by flame, is when there is a direct combination of oxygen with hydrogen in the forming of water.

In the case of flame, however, the buoyancy of the hydrogen carries the heat upwards so rapidly that it spreads less in lateral directions than when there is no flame, and the heat produced is really not so intense. In the flaming fire made of coal that contains a large por-

tion of hydrogen, such as cannel coal, which is a valuable kind for gas works, the flame and heat, when not confined, go up the chimney; and the ascent is so rapid, that a part of the carburetted hydrogen goes in the same direction without undergoing the process of combustion.

The union of oxygen with carbon, when there is no other substance present, demands a much greater heat to set it going; and although the momentary heat produced is not so great, and the light not so brilliant, the products have not the same buoyancy; and the heat in consequence spreads more in the lateral direction. A fire composed in part of coke or cinders is the best for heating a room; and also for any purpose where a great and steady heat is required. There is also comparatively little smoke from a charcoal fire, as there are few or no ingredients in it (if pure) that form anything but carbonic acid. But in proportion as the smoke is harmless, the other product of the fire is dangerous, more especially in close apartments, in which there are no openings lower than the floor of the fire. If there are not, the carbonic acid accumulates, and to those who breathe it, it is dangerous, and soon fatal. The accumulation of carbonic acid gas in an apartment cannot well rise higher than the fire, because, if it did, the fire would be extinguished; but it is very hazardous to sleep in an apartment where there is a fire of charcoal, unless there be a free means of escape for the carbonic acid lower than the bed.

Section XC.—Production and Relations of Heat and Light.

In our common notions of heat and its accompanying light, we always have expressed or implied allusion to the burning of ordinary fuel in atmospheric air, or the heating of more stubborn substances than the fuel by the heat so produced. But these form so small a part of the whole subject, that, without much more knowledge, we should be very ill fitted for understanding the nature and laws of

those actions, spontaneous or artificial, which are accompanied by the development of light and heat; and if we attempted to found any general theory, or doctrine of light and heat, upon even the most correct and philosophical view of so limited a portion of the subject, we should so hamper ourselves in error, that there would be great difficulty in learning any more. We should be in the same situation as the 'bee,' in the fable, which having tasted nothing but honey, came to the general conclusion, that 'all things were sweet,' but found itself wofully mistaken when it went to quaff the honey-coloured decoction of wormwood.

This is a caution of such universal consequence, and so apt to be lost sight of, not by the young and the ignorant merely, but by the most experienced in partial pursuits, that it can hardly be too often repeated. We are never certain, even in those cases to which we have paid the most minute and careful attention, that we have carried our analysis down to the absolutely simple fact or substance; and, therefore, we must beware how we decide one case upon the evidence of another. Where men make the law, precedent is a very proper rule of judgment; because the law itself is nothing but a precedent—the opinion of those who made the law, formed from the evidence of which they were in possession. But there are no laws of human enactment in philosophy, or in science of any kind; and, therefore, in these there can be no safe judgment from precedent.

All that we can confidently say in a general manner respecting heat is, that it is one of the appearances which accompany the action of bodies. In some cases it is the only appearance that we can trace, and in others it is not; but the mere heat does not tell us what the action is; nor can we say that different degrees of heat, as measured by our feelings or our thermometers, are the measures of different degrees of action; though, if all other circumstances were the same, this conclusion would be philosophical, or, at all events it would be all that we could get

for philosophy. But the difficulty is in knowing whether all the other circumstances are the same.

So also light always accompanies certain developments of heat; and where the circumstances are the same, we have reason to believe that the intensity of the one is in proportion to that of the other; though in this case, the similarity is attended with the same difficulty as in the other.

The actions of different bodies upon each other are all different; and, indeed, except variations in external appearances, which is a very deceptive matter in many instances, difference of action is the only test of difference of substance.

The state of bodies has very considerable influence upon the degree of heat which is accompanied by a certain degree of light. We are not warranted in saying, that the intensity of light at the same degree of heat is exactly in proportion either to the cohesion or the density; but there is some relation between these and the development of light. Solids become luminous at much lower temperatures than liquids, and liquids at much lower temperatures than gases. In these cases we may conclude, that the cohesion of the solid retains the particles in the 'place' of the heating action, while the greater mobility of the liquid allows of their escape from it; and the perfect mobility of the particles of the gas allows it still more. Melted lead, in which there is no appearance of redness, will kindle a stick: and a platinum wire held near the flame of a lamp, will in time show a white heat, although there is not the faintest development of light in the air which so warms it. Many analogous instances might be given; but it is difficult to perform experiments at high temperatures in the open air without effecting decompositions or combinations; and these always modify the results.

Though it is probable that in the action of particle upon particle, by which the smallest imaginable extent of the appearance is produced, the intensity of the heat and light is the same in every instance,—that is, that they vary

according to the same law, yet either may appear greater, according to circumstances. The intensity of the visible flame depends on the rapidity of the action, and the number of particles in a state of action in the same space; but this has its limit. Thus phosphorus, and those substances which are called phosphorescent, from their shining in the dark,—such as putrid fish, many little animals in the sea, rotten wood, those gases that form *ignes fatui*, and the phosphorescent light given out by glow-worms, fire-flies, and some other insects,—are luminous at low temperatures, and without much sensible heat. Still the action of particle on particle is just as great, and the minute portion of light as brilliant, as if they were in a state of the most rapid combustion, only the active particles are so few in a given space, that they have little sensible action as heat, and only a faint one as light.

Indeed, in order to convince ourselves of this, we have only to produce a more rapid union of the phosphorus and oxygen, in order to procure the most brilliant light and most intense heat. In common air at a temperature of 148°, when the air shows not the smallest indication of light, phosphorus burns rapidly with a white light; and when placed in oxygen, even at a lower temperature, it inflames spontaneously, and the light is intensely brilliant, and the heat corresponding. Greater light and heat appear, therefore, to be, in most cases, the accompaniments of more rapid and concentrated action, and not of action of a different kind.

Another remarkable instance of the variation of heat with that of the rate of combination between two substances, occurs in the case of *chlorine* and *hydrogen*. These form *hydrochloric acid*, and that with *soda* (*hydrate of sodium*) forms common salt. Chlorine and hydrogen both exist naturally in the state of gases; the acid which is formed by their combination is also a gas, into which they enter in equal bulks; and the bulk of the compound is exactly that of the two ingredients. The specific gravities, and consequently the densities, of these

gases, is very great, chlorine being about thirty-five and a half times heavier than hydrogen.

Now, whether the great difference of specific gravity be or be not the cause, we cannot say; but when a mixture of equal parts of them is kept in a dark place, they have little or no action upon each other. But if they are exposed to day-light in the shade, they combine readily though silently; and if exposed to the direct sun-beams, they combine with an explosion, or a display of light and heat. These are, however, mere accompaniments of the rapid action; and when this is over there is no change of bulk.

The disengagement of chlorine from its combination with nitrogen, the latter of which is understood as being the passive ingredient of the air in ordinary combustion, is attended with most violent action of light and heat. The compound is an oily liquid, of which, if a drop the size of a pin's head is touched with a bit of phosphorus, it explodes in the most violent manner. It seems, indeed, that the violent mechanical action in all explosions, is produced by the rapid expansion of nitrogen, as is found in gunpowder, and in all the fulminating preparations. When nitrogen is not present, the action is not so violent, and the progress is slower. Artificial lights are made generally of preparations containing chlorides; and they are set on fire by dipping in sulphuric acid, by rubbing, or by striking the paper in which they are contained, according to the nature and proportion of the ingredients.

Section XCI. Principal Applications of Heat and Light.

Those actions of bodies in which heat and light are displayed, are applied to three distinct classes of purposes, each of which requires a different modification. These purposes are, mechanical effect, chemical effect, and illumination.

When mechanical effect is the object, it is necessary that the action should be as violent and as sudden as possible; and this is most successfully done by separating, in the state of gas and at a very high temperature, some substance which previously existed in the solid state, but which does not combine into a solid product by the process. Nitrate of potash is the substance used for this purpose in common gunpowder, to which sulphur is added, on account of its inflammability, and charcoal, for the heat that it produces. As the detonation of the nitrate of potash, (nitre, or salt-petre,) which is the real force of the powder, does not take place except at a red heat, the powder must be inflamed by a match, by sparks struck burning from steel by the rapid percussion of a flint, or by some of the fulminating chlorides that can be fired by a blow—as is the case in percussion or detonating guns. In fire-arms, this is the method that requires the least force, and therefore it may be considered best for taking a good aim; but the flint and steel are much less liable to accidents.

Gunpowder, when in a solid mass, or in a fine powder rammed hard, does not explode; but it burns with great heat. The reason is, that heat makes its way slowly through it. Hence it is reduced to grains; and, if they are such as to preserve openings between them, the small grains explode most readily. The gaseous product is carbonic acid and nitrogen, in nearly equal parts, with some sulphurous acid, and less or more of free sulphur and charcoal, according to the quality of the powder, and also sulphate of potash and sulphuretted hydrogen. The last is decomposed, and causes the offensive smell when a gun is washed after being discharged.

The effect of gunpowder, or of the recently-invented substance gun-cotton, in producing motion, or overcoming resistance, is not in proportion to the loudness of the report. The report is loud in proportion as the action is immediately communicated to the air; but the effect is greater when the explosion spends its initial energy on

solids. It is also necessary for producing the greatest possible effect, that the ignition of the whole charge should take place nearly as possible at the same instant; and where the cohesion of matter is the resistance to be overcome, as is the case in the blasting of rocks, the force is augmented by the admixture of some foreign substance, such as dry saw-dust.

An explosion is a very momentary action, the power of which is limited to the act itself, and is not in any way dependent on extraneous circumstances. It cannot be maintained as a continued power for the producing of a regulated and protracted effect. Each explosion resembles the blow of a hammer, which produces the whole effect in its fall, and would not increase it if left where it strikes. The only way, therefore, of obtaining continued action is by a succession of explosions, the one of which acquires no momentum or greater force from the other, though, as is the case in hammering iron, the sum of the whole may be made to bear upon one object.

When the expansive force is produced by some cause that acts only on changing the volume or state, and not the composition of the expanded substances, the exertion of the force may be regulated and made continuous; though in these cases also, when there is an explosion, the power is soon at an end. In the common method of employing the steam or vapour of water as a power, the effect is produced by a series of expansions and condensations; and even in the most skilfully constructed steam-engines, the whole effect of such expansion is lost in the condensation,—the great advantage consisting in the heat of the vessels being kept up; and thus little more consumption of fuel is occasioned than is necessary for producing the steam. In principle, this is perhaps the highest degree of perfection that can be reached in the application of expansion by heat as a regular mechanical power. The degree of force that may be given to it depends not on a different principle, but on the strength of the containing vessels. Steam escaping from an aperture, and acting

directly on the floats or buckets of a wheel, might afford a continued power without any alternating condensation; but this would work at a loss, as compared with the engine; the same quantity of fuel being required to raise the steam as in the former case, and its strength would be greatly diminished before it could take effect.

To detail the chemical effects which are produced by the application and management of heat and light would involve much of the science of chemistry, and many of the operations in the arts; consequently, all that we can do is merely to notice the general principle.

Some of the most striking chemical effects are produced by those phenomena which are termed *electrical;* and as the most powerful degree of these produces no effect upon the weight of the substances acted on, which is the only measure we have of the quantity of matter, we have no rational ground for concluding that there is any more matter present when substances exhibit the most intense degrees of those actions, than when they exhibit none whatever. These phenomena, like those of heat and light, when produced by different means, may be so gentle as not to display either sensible heat or visible light. In these cases there is little action, just as there is when neither heat nor light is apparent; and in proportion as the action becomes violent, the heat becomes intense and the light brilliant.

The effects are, making allowance for differences in the modes of application, just the same as in cases of other heat. At a certain degree phosphorus burns, and, a little higher, spirits of wine. Common fuel burns, iron is burnt, platinum melted, the alkalies and most of the earths decomposed; and in all cases where we have the means of examining it, the chemical action is just the same.

The most splendid exhibition of combined light and heat with which we are acquainted, is that produced by the transmission of a powerful current of voltaic electricity through well-burnt charcoal; small pieces of that substance, terminating in fine points, being attached to

each pole of the battery. This is not analogous to ordinary combustion; for although the *light* is so brilliant that no eye can look upon it without pain, and the *heat* so intense that the most intractable substances are readily fused, yet the charcoal is only very slightly affected. It is also proper to mention that the light and heat can only be produced in a space between the points of the charcoal, and not when they are actually in contact. This is more powerful action than we can obtain by common fires without the aid of a third substance. The utmost that we can obtain in a boiler, heat it as we will, is steam, unless a portion of the oxygen of the water combine with the substance of the boiler, and set the hydrogen free. That does not take place rapidly at lower heat than that which would at the same time loosen the tenacity of the boiler, and it would be blown to pieces. These modes of action, which, when intense enough, are accompanied by displays of light and heat, cannot, however, be fully understood without more of detail than can with propriety be given in this volume.

All flame, occurring under ordinary circumstances, may be considered as the tranquil combination of some inflammable gas with the oxygen of the atmosphere; and when the flame is very bright and white, it may be considered that hydrogen and carbon constitute its principal ingredients, and that part of the products must be carbonic acid and water. (See page 213.) If the gas, though even of the best kind, and whether produced spontaneously from tallow or oil, or previously prepared from coal, is supplied in too great proportion to the oxygen that can mix with it, carbon in a solid state will be separated, the intensity of the light will diminish, and smoke be produced. That smoke, and especially the denser part liberated from coal, may be consumed by passing it over substances strongly ignited; but, generally speaking, flaming fires do not produce the most steady heat, because the flame is volatile, or mounts up. Flame, also, will not bear a blast of any great force, as may be seen by blowing

out a candle. If the candle is snuffed so that the wick is within the flame, the wick appears black, as no oxygen gains access to it; but the moment that the flame is blown out, the wick becomes red, and the charcoal ignites, leaving only ashes in place of that portion which appeared black while the flame lasted. Not only so, but if it be done before the burning of the charcoal has advanced too far, the flame may be blown in again by the very same process that blew it out. Hence when a powerful and steady heat of long continuance is wished to be obtained by common air, either naturally or by an artificial blast, charcoal is much better than those matters which burst into flame;—the general principle being that the fuel in this case bears the blast, whilst the heat is not dissipated.

Section XCII. Light from Combustion.

The light which is given out during the combustion of those substances which yield flame, is one of the most useful applications of this process; and it is one of which it may not be amiss very shortly to state the necessity.

Without taking the atmosphere into consideration, every place on the earth's surface may be said to have six months of day and six months of night in the course of every year; only, they who live under the equator have them divided into equal portions every twenty-four hours; and they who inhabit other places have a seasonal division, which becomes more marked as the latitude increases, till at the pole, the whole light is accumulated into one summer day, and the whole darkness into one winter night.

But the atmosphere, being globular and transparent, acts as a lens, and makes the light, which passes through it round the earth, converge towards the point opposite to the sun, and thus fall upon and enlighten—in its progress towards that point—a zone of the earth's surface extending some distance beyond what would otherwise be the boundary of light and darkness.

The height to which the atmosphere is of such density as to refract even faint twilight, is, however, very small, compared with the diameter of the earth; and its density diminishes very rapidly within those limits, so that the refraction extends only over about eighteen degrees round the enlightened hemisphere. Of this zone, the *entire* light of the sun extends to a very minute portion; and the rest fades gradually away, as we find in the twilight.

The measure from the centre of a hemispherical surface to the circumference is ninety degrees, so that the region of night, or total shadow, always extends eighteen degrees less than that, or seventy-two degrees round the point opposite to the sun. Of course, if any place is more than seventy-two degrees from the point opposite to the sun, that place must have either direct sun-light or twilight; direct light if more than ninety degrees, and twilight from seventy-two degrees to ninety degrees.

At our midsummer, the point opposite to the sun is about twenty-three degrees and a half north of the equator, or sixty-six degrees and a half from the north pole. Consequently, at that time, all places beyond sixty-six degrees and a half north latitude must have continual day; and all places beyond forty-eight degrees and a half, which includes the British islands, twilight during the whole absence of the sun. But the twilight from the upper and rarer portion of the atmosphere is very faint, so that, in the south of England it is barely perceptible, while in the north of Scotland midnight is much lighter at midsummer, than mid-day at London on a foggy day in winter.

But still, notwithstanding their long twilight, the people of those northern climes have abundance of darkness; and if they could not remove it by artificial light their condition would be very wretched.

The productions of nature harmonize so well with the necessities of man in all places, that where artificial light is most wanted, the materials are most abundant. In the countries near the pole, the animals, such as whales and

seals, and other warm-blooded inhabitants of the sea, and also the sea-birds, abound in oily fat. In the sea animals, much of this fat is fit for the lamp without any preparation; and some of the birds are so full of oil, that the people draw a wick through their bodies, and burn them like candles. In the tropical countries, again, where the land animals have little fat, vegetables afford an abundant supply of oil. Many of the palms, and not a few of the herbaceous plants, are very rich in this substance; so that they supply the want of animal oils, both for light and for other domestic purposes. Even the earth itself affords supplies, of which some are met with in almost every country which can be named; and in a part of Asia, to the north-east of the Bay of Bengal, the springs of *petroleum*, or mineral naphtha, are so abundant, that they give great value to a place otherwise unproductive.

Sometimes the more inflammable part of the naphtha is given out by fountains, or from fissures of the earth, in the state of gas. This gas is much more easily set on fire than the liquid products; and hence, in times when there was little science, it was taken advantage of for superstitious purposes. Science has pointed out the means of obtaining abundant supplies of gas, from coal, from oil, and from other substances; and its advantages in lighting streets, manufactories, shops, and private dwellings, are incalculably great.

In all cases of artificial light from oleaginous substances, whether solid as in candles, or liquid as in common lamp oil, a wick is necessary to regulate the supply of the vaporized material to the flame. The wick is generally made of cotton, or some substance which burns at a lower temperature than tallow or oil, and it is therefore liable to become coated with charcoal. Hence the necessity of frequently snuffing candles and of trimming lamps, which is merely removing the unburnt portions of the tallow or oil, which being deposited on the wick, destroys its capillarity.

With a closely-twisted wick, such as that of a candle

for instance, it is impossible to obtain more than a certain quantity of light without smoke. As the oxygen of the atmosphere has access only to the exterior surface of the flame, whenever the latter is enlarged by loosening the fibres of the wick, or by any other means, the tallow is melted faster than it can enter into a state of perfect combustion, and then the candle gutters, its light diminishes, and smoke is produced.

The argand lamp which admits air to both sides of a thin wick placed between two cylinders, is an improvement, and it is the better, the more completely the oil is kept up to the very top of the metal, and the lower the wick is. This can be done by a regulated pressure on the oil vessel; but it answers only for lamps that are stationary, as the oil flows over if they are carried about. Indeed, if an argand lamp be lifted suddenly upward, even for a few inches, it is apt to be extinguished by the resistance of the air beating down the flame. Still the argand lamp is a very great improvement, both for the central current of air which it admits, and the glass chimney which protects the flame. With an open flame, the process of extinguishing is constantly going on all round the flame by the cold air; but the air in the chimney of the argand lamp, has a very high temperature, and thus the flame continues steady; and if the supply of oil be properly regulated, the combustion is complete, the wick hardly burns at all, and there is little or no smoke. Argand lamps are made to burn those oils (such as cocoa-nut oil) which are not liquid at the common temperature of the air, by means of a piece of metal heated by the flame; but if the supply be not very nicely adapted to the consumption, the metal is apt to get coated with charcoal, and then the lamp burns badly. Very tall chimneys upon argand lamps diminish the height of the flame, but greatly increase its brilliancy; they are not, however, so economical as those of the ordinary height.

Section XCIII. Light-houses and Signal Lamps.

Though common lamps and candles answer well enough for diffusing light over short distances, yet their effect is very limited in consequence of the divergence of the light; and thus they are of inferior use as beacon-lights at sea, when it is necessary the light should be seen at the distance of several miles.

Beacon-fires, of coal or other fuel, were probably first used for this purpose; but these were expensive, required constant watching, and fatal accidents sometimes happened by mistaking fires on the land for them. These inconveniences and dangers increased with the increase of navigation. Numbers of candles, or large lamps, with concave reflectors behind them, lined with small pieces of mirror, formed the first improvement; but the smoke always impaired the effect.

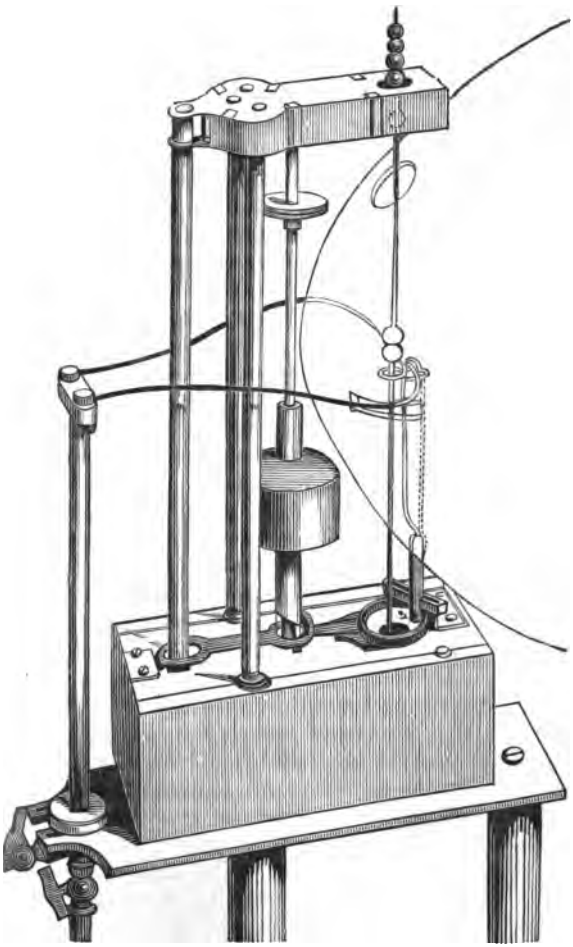
It is a well known property of the paraboloid, that rays of light diverging from its focus, and falling on the concave surface, are all reflected parallel to the axis, and of course, to each other; so that, if it were possible to place a sufficient light in the focus of such a curve truly formed and perfectly polished, a light would be obtained, which, in ordinary states of the atmosphere, would be visible within any distance where the view was not interrupted by the curvature of the earth.

But the forming of the paraboloid is a very difficult process, as it must be done by hand; and the polish is also difficult, as it must be rubbed or ground, and not burnished. The focus also is a mere point; and the lamp requires some space—those of the common light-houses are seven-eighth of an inch in diameter; so that the best of these is only an approximation. Still, when properly made, such a light may, in clear weather, and if sufficiently elevated, be seen at the distance of thirty or forty miles. The adaptation of this reflector to argand lamps was the second improvement; and it is still used in the best British light-houses.

The next improvement (though, indeed, something of the kind had been previously tried in England and had failed) was the French lamp with the polyzonal lens. The light is from an argand lamp three inches and a half in diameter, with four concentric wicks, and air, of course, on both sides of each. The lamp is so contrived as that the supply of air shall be ample, and the oil kept up to the flame in all the wicks, so that it burns very brilliantly, and with little smoke. The lenses are composed of separate pieces of glass, and each lens is thirty inches in diameter. The light from this lamp is far more brilliant than that from a common argand with a reflector. But the chief advantage is in the large lamp and the copious supply of air between the concentric wicks. The lens is very costly, and difficult to be made so as not to consume or scatter a good deal of the light by refraction. If it were possible to bring so large a lamp into the focus of a parabolic reflector, which of course it is not, the effect of an equal combustion would be far more brilliant.

The grand desideratum was, therefore, to find some species of combustion which should furnish light enough from a very small object in the focus of the paraboloid. This was accomplished with complete success, in 'DRUMMOND'S LAMP,' of the essential parts of which a figure is given on the opposite page. The flame of this lamp is produced by the combination of oxygen and hydrogen in forming water; and, therefore, it has been called the *oxy-hydrogen* or *hydro-oxygen* lamp. Both these names are improper, as a blow-pipe (which is in fact a lamp, only it is for chemical purposes, and not for light) consisting of the same gases and in the same proportions, was well known before Lieut. Drummond's invention; but he first applied the reflector.

The principles of the lamp are these:—An inflamed jet of the mixed gases, in the proportions of 2 volumes of hydrogen to 1 volume of oxygen, (the light from which is hardly perceptible, whilst the heat is the most energetic known to us,) is directed against a small cylinder of lime,



LIEUT. DRUMMOND'S LAMP.

and as soon as that has attained a certain temperature, it becomes phosphorescent, emitting a light of great intensity. The light thus obtained, very closely resembles, but is not quite so white as, that produced by voltaic electricity (page 312). The lime is not actually consumed, but merely heated and vaporized,—the particles thus separated causing the intense whiteness of the light. The only product of the lamp is pure water. The advantages of this light are that in brilliancy it is immeasurably superior to that obtained from oil lamps, whilst the space it occupies is much less, and therefore it acts more effectively around the focus of a paraboloid reflector.

The curved line through which the wire supporting the little balls of lime passes, is part of the paraboloid (which we shall call the reflector); and the lower of the two balls is in the focus—the place where it acts as a wick.

The line passing through the balls is a wire of platinum, which is the metal best adapted to bear the intense heat. The uppermost of the two balls is one ready to supply the place of that under it when the latter becomes unserviceable, and by being placed near the other it becomes so hot before it takes its place, that the light is not interrupted. Both balls are supported by the little stop, which is pushed aside when the lower one is worn; letting that drop down the wire, but retaining the other in its place.

The balls on the top of the wire are a supply, with which the lamp feeds itself. Each ball lasts about forty-five minutes, and the succession ball is let down about two minutes before the preceding one is dropped.

The wire which carries the balls revolves once every minute, by means of clock-work below; and the clock-work also shifts the balls. Thus the supplying of what may be called the incombustible wick of the lamp is self-performed except placing the balls on the top of the wire; and four of them last three hours.

The balls are composed of pure lime, calcined, and reduced to an impalpable paste by slaking; and then con-

solidated by great pressure in a wooden mould, which forces out the water. The balls are then turned in a lathe. They are three-eighths of an inch in diameter, or have not much more than one-sixth of the surface which the flame of the argand lamp presents.

The oxygen and hydrogen are retained in separate gas-holders (not shown in the figure), which are constructed so as to regulate the proper discharge from each; and these gas-holders are loaded with a pressure of about one atmosphere.

The two gases are let in by the stop-cocks at the bottom of the tube-pillar, at the side most distant from the reflector. They ascend this pillar by separate tubes; and are mixed in a little reservoir on the top of it. After the gases are mixed, they are passed through three screens of wire-gauze to prevent accidents from explosion, and then they act upon the ball through the two bent tubes, which pass from the top of the pillar-tube, and enter apertures, on the opposite sides of the reflector, their apertures, and consequently the jets, being directed on the opposite sides of the ball, which soon acquire a most intense white light. So intense, indeed, is the action, that, but for the rotatory motion of the ball, the jets would soon drill it through; and as it is, they soon cut a channel round it, and would in time cut it in two, which is the reason for replacing it as has been stated.

The experiments which were made with Drummond's lamp in 1830, show very clearly the superiority that it possesses over every other. The following are the comparative results, estimated in wax candles one inch and one-eighth in diameter:

		Candles.
Seven-eighth inch oil-gas burner . .	equal to	$8\frac{7}{10}$
Seven-eighths argand burner (pure oil) .	equal to	$9\frac{1}{10}$
French lamp and lens	equal to	$94\frac{8}{10}$
Drummond's lamp	equal to	$122\frac{9}{10}$

The advantage of having the light from a small body in the focus of the reflector, for the purpose of throwing a

distant light, is very conspicuous in the comparison of Drummond's lamp with the common argand lamp and reflector. The divergence or spread of Drummond's was found to be only six degrees twelve-hundredth parts, while that of the argand was seventeen degrees forty-hundredth parts. So that, whatever may be the relative intensities of the original light, that from the argand lamp occupies at an equal distance, about eight times as much space, and, therefore, must have only one-eighth of its original intensity, as compared with the other. The divergency with the French lens is less than that with Drummond's lamp, but a certain portion of the light there is lost in passing through the lens.

In making direct experiments on the intensity of the light through equal apertures, it was found that Drummond's lamp is equal to 264 argand lamps and reflectors; but the argand lamp throws its light upon about eight times the area, so that in absolute quantity, or degree of light, the lamp is just equal to thirty-three argands and their reflectors.

In a fixed light, the object of which is, that it may be seen for a considerable length of run along a coast, and not at a very great distance, the argand lamp has the advantage of being visible for about three times the line; but where the light has to be seen at great distances, and in the case of revolving lights, Drummond's is far preferable. Nor is the expense much greater. The inventor estimated the hourly expense of one of his lamps at four cubic feet of hydrogen, and two of oxygen, which cost about *fivepence*. He further stated that six of his lamps would afford twenty-six times the (intensity of) light of thirty argands in a reflector each; and would cost 2*s*. 6*d*. for gas, while the argands cost 2*s*. 1*d*. for oil. The reflectors are the most expensive part of the construction; and as five times as many are required with the argands, the erection of Drummond's lamps would be cheaper. The chief objections are, the nice management which the lamp requires, and the difficulty of making, and the danger

of keeping, a large supply of oxygen and hydrogen gases in a light-house.

The Drummond lamp was first used by its inventor, as a night-signal, in the trigonometrical survey of Ireland. It was then supposed that it could be made practically available for light-houses, and other useful purposes; but, like very many ingenious inventions, founded on truly philosophical principles, it proved be too costly, and too difficult to be managed by persons usually employed as light-keepers. We retain the description and engraving of the apparatus, not merely as a record of what has been done; but because it is not at all improbable that some improvement hereafter may be made in it, which will so simplify the arrangements as to adapt them to every-day purposes.

The oxy-hydrogen light has been employed as a substitute for that of the sun in an arrangement similar to the solar microscope. Several of these instruments have, during the last few years, constituted very attractive, as well as highly interesting, public exhibitions. On a smaller scale, and in a more convenient form, they are used in the prosecution of physiological researches.

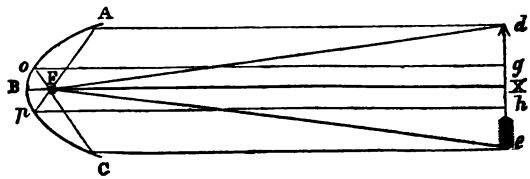
Section XCIV. Parabolic Reflectors.

The effect of parabolic reflectors in throwing an artificial light to a great distance and with great comparative brilliancy, is so great, and the applications of it, not only for maritime purposes and night-signals, but in many of the common arts of life, might be rendered so advantageous, that the principle of the reflector demands a little more notice than that at p. 317.

A parabolic reflector, or paraboloid, (though that is properly the name of the solid of which the reflector is the surface,) has its base or open extremity a circle, and all sections parallel to the base are also circles. All these circular sections have their centres in the axis of the paraboloid, and their planes are, of course, at right angles

to that axis. All sections passing through the plane of the axis, in whatever direction, are equal parabolas, and they are at right angles to the base and to every circular section parallel to the base. Any of those parabolic sections divides the paraboloid or its surface into two equal and similar parts, but those parts are symmetrical; that is, the one of them is turned to the right hand, and the other to the left, just as is the case with the two halves of an animal, or any other symmetrical body, when supposed to be divided into equal parts by a longitudinal section.

Such is the form of the reflector; and its action and the effect may be illustrated by the following diagram:—



Let the curve A B C represent a section of the reflector, in which a line drawn from A to C represents the diameter of the base, or opening, or greatest extent of the reflector in breadth. The point B represents the apex or deepest point,—that farthest from the base; and the straight line from B, continued to X, is the axis, passing through the centre of the reflector, and also of the beam of light which the reflector sends forth when used.

F is the focus of the parabola, and the dot at F may be understood to represent a light placed in that focus. The place at the focus depends upon the relative lengths of the axis and diameter of the base, the varying lengths of which afford an unlimited number of parabolas, but all of them possessing, in equal perfection, that property which renders them so useful as reflectors.

That property may be thus described—upon whatever point of the concave surface a ray of light from the focus

falls, that ray is always reflected parallel to the axis; and, therefore, the whole light which falls upon the concave surface, from a light in the focus, is reflected outwards in a cylindrical beam of the same section as the base or opening of the reflector, and having no tendency to diverge or spread, excepting what may arise from the imperfection of the reflecting surface, or the state of the air or other medium through which the light passes.

The lines F *o* and F *p* may be considered as any two rays of light proceeding from the luminous body at F, and falling upon the concave surface at the points *o* and *p*; and the lines *o g* and *p h*, from these points parallel to the axis, are the positions of the same rays as reflected.

Light proceeds from a luminous body, in innumerable radii equally divergent on all sides; consequently in the section, all the rays from A F, round by B, to C F, will fall upon the parabola; and as the reflector is a parabola in every section, the whole light contained in the sector of a sphere, of which the retroflected angle A F C, greater than two right angles, is the angle, will fall upon the surface of the reflector, and be projected outwards in the cylindrical beam. The supplement of the retroflected angle, that is, the angle contained by A F and F C outwards from the curve, will represent the portion of light which does not fall upon the reflector; and by which only, or part of it, any object, such as *d e*, would be illuminated if the reflector was not there.

Let us now compare the illuminating effects. At the very aperture of the parabola it will be seen that the section of light falling upon it is, in the figure, about double that which does not so fall; but lights from surfaces are as the squares of their sections; and, therefore, the light reflected from the parabola close at the aperture is four times as much as that not so reflected. But a surface placed at the aperture has the advantage of both; and, therefore, in a parabola of the same curvature as the figure, an object at the aperture would receive five times as much light as if the parabola were not there. The

proportion of these quantities depends on the curvature of the parabola, and the distance of the focus within its base; and, therefore, it may be greater than what has been stated, or it may be less, in an unlimited number of variations.

But the grand object of the parabolic reflector is to obtain light at long distances; and then its superiority becomes very striking. Let *d e* be an object at a moderate distance; join F *d* and F *e*, and the small angle *d* F *e* will represent the section of the direct light which can fall upon *d e* from the light at F, while the reflection from the parabola projects four-fifths of the entire light the same as before. The diminution from atmospheric or other causes need not be taken into the account; because it is greater in the direct divergent light than in the reflected parallel light.

d e is at a very short distance, and yet it will be found that the direct light which it receives is not one-hundredth part of the reflected light; and if it were removed a hundred times farther, which would still be but a short distance, the direct light upon the line would not be above one ten-thousandth of the reflected light; and if the removing were continued, the direct light would entirely vanish long before there were any sensible diminution of the reflected light. Other than that which is absorbed or scattered by the medium through which it passes, there is no source of diminution to the quantity of light once projected from a parabolic reflector.

One of the most desirable objects in the investigation of powerful reflected lights, would be to find one which should penetrate a thick fog to the distance of a mile, or even half a mile; because such a light would be of great service in protecting ships from banks and rocks in foggy weather. Whether the object is possible or not, is, in the present state of our knowledge, a doubtful matter. Perhaps no artificial light can be expected to possess more penetrating power than the direct light of the sun, and that light certainly does not penetrate a hundred

yards through the thickest London fogs; while the light of a common gas-lamp in the streets does not penetrate above fifteen or twenty yards. Sea fogs contain no smoke, however, and therefore they are much more penetrable than the London fog; but whether the combustion of the gases on lime, the combustion of charcoal by a powerful galvanic battery, or any more or less intense light, either white or coloured, which may hereafter be discovered, shall penetrate them to the distance desired, is a matter of experiment, and an experiment which certainly deserves to be made.

Section XCV.—Electricity.

If certain substances are rubbed together they exhibit properties which cannot be observed under ordinary circumstances. Thus, if sealing-wax, or sulphur, or glass, are rubbed in a particular manner with dry silk, or a piece of woollen cloth, they attract light substances, such as paper, feathers, fibres of cotton, and small particles of dust. The principle, which by these simple means is brought into action, is called *Electricity*, from the Greek word ηλεκτρον (electron), amber; electrical phenomena having been first noticed in that substance.

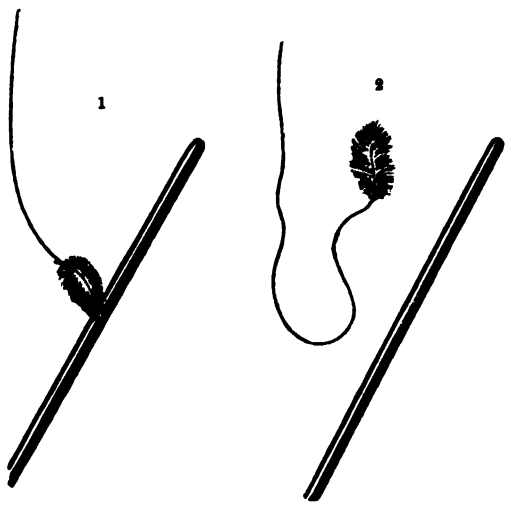
Let it be observed that electricity is believed to be a property common to all bodies. It is, however, more readily excited, that is, rendered manifest to our senses, in some substances than in others; which depends, as we suppose, not on there being, so to speak, a greater quantity of electricity contained in one class of substances than in another, but on the relative conducting powers of different substances and the facility with which the electricity they contain may be developed.

The electricity produced by friction is called *common* electricity, to distinguish it from that which is the result of chemical action. We do not profess to understand or explain the true nature or cause of electricity. Our business is to describe some of its effects; and in doing this we are obliged to employ terms which, for aught we know

to the contrary, may, in a philosophical sense, be very inappropriate; but if they assist us in explaining the general principles of this interesting branch of science they answer the purpose intended.

There are supposed to be two kinds of electricity, or, if not two kinds, we are certain that the electricity excited in two different substances, and in some cases on opposite sides of the same substance, is essentially different in some of its properties. We can best explain this by an example.

Let us provide the simple apparatus denoted in the following figure, which consists of a piece of glass tube,



say about thirty inches long and three-fourths of an inch diameter, and a small downy feather attached to a piece of slender white sewing-silk, and suspended in such a way that it shall be at least three feet distant from all surrounding objects.

The tube being clean and dry, if we rub it briskly with a dry and warm silk handkerchief, it will be thereby elec-

ically excited, and on bringing it near the feather, the tter will be attracted and adhere to the tube. On gently parating them and again presenting the tube, the feather ill be repelled, and for some little time it will be found ıpossible to reunite them. In a minute or two, how-er, and without any apparent change of circumstances, e feather will again be attracted by the tube, and then pelled, and so on alternately until the electricity of the be is expended, but which may be renewed as often as ay be desired by rubbing it with the silk. The figs. 1 d 2 represent the feather attracted and repelled as above scribed.

From these simple experiments we learn the following ıportant elementary facts, namely, that there are two nds, or, at any rate, two opposite states of electrical tion (we like the latter distinction the best); and that dies which are in opposite states of electrical excitement *tract*, whilst those which are in similar states *repel*, each her. As respects the attraction and repulsion exhibited the glass tube and the feather, it is proper to remark at we described them according to appearances; but it ll of course be understood that the attractive and repul-ve energy was mutual, that is, the tendency of the ıther and of the glass to unite, or separate, was pro-rtionate to their respective weights and the quantity of ctricity they contained.

But we may still further illustrate this principle, which s at the very threshold of electrical investigations, if we ke a stick of red sealing-wax and rub it with a roll of y and warm flannel, when on presenting the wax to the ıther it will be first attracted and then repelled, as eady shown; but if we apply the excited glass tube to e feather, and when it is saturated with electricity and *pelled* by the tube, if we bring the wax near it, it is stantly *attracted*. We may reverse this experiment by arging the feather with electricity from the wax, when will be attracted by the glass. Hence it is manifest ıt the electricity developed by rubbing glass with silk

is different from that produced by rubbing sealing-wax with flannel.

A slight variation in the experiments just noticed will teach us another instructive fact, and which is one of the fundamental laws of electrical action, namely, that as any two bodies when rubbed together and which exhibit electrical phenomena are in opposite states of electrical excitement, it follows, that one state of electricity cannot be produced without at the same time, and by the same means, producing the other. For instance, if that part of the silk which was in contact with the glass tube, during the process of rubbing, had been presented to the feather at the moment when it was repelled by the tube, it would have been attracted by the silk. The same remark applies equally to the sealing-wax and the flannel.

The two kinds, or as we have preferred calling them, the opposite states, of electricity, used to be described by the terms *vitreous* and *resinous;* a distinction which originated in the circumstance to which we have already referred; which is, that the electricity produced by the friction of glass is different from that which results from wax and other resinous substances.

The terms now commonly employed to denote the opposite states of electrical action are *positive* and *negative* —the first being substituted for vitreous, and the last for resinous, electricity.

Those substances in which electricity is easily excited are called *electrics*—whilst those of an opposite character are termed *non-electrics*. Electrics are also called *non-conductors*, and non-electrics by the same rule have received the name of *conductors*. A class of substances intermediate between the two extremes is called *imperfect conductors*. When a substance, which in its ordinary state is a conductor, is attached to another substance which is a non-conductor, and in such a way as to prevent the electricity which may be excited, or accumulated, in it from escaping, the former substance is said to be *insulated*, that is, cut off from electrical communication with the earth and other surrounding objects.

Section XCVI. The Electrical Machine.

There is no department of natural science that affords a greater variety of instructive experiments than electricity. For young persons we look upon an electrical machine, and some judiciously-selected articles of apparatus, as constituting one of the most valuable gifts their friends can bestow; their use, even as an amusement, insensibly leading the mind away from the common and, too often, frivolous, pursuits of youth, towards the contemplation of those ennobling principles which are inspired by just perceptions of Him who upholdeth all things by the word of his power.

Already have we mentioned that of the true nature of electricity we willingly confess our ignorance. It may be an extremely subtle form of matter, forcing itself between, and obstinately adhering to, the particles of all other material substances. Or, perhaps, it may be a condition essential to the existence of matter, as at present constituted, and by its all-pervading and mysterious agency perpetuating the phenomena of decay and reproduction in their endless variety. Whatever it may be, we have abundant proofs of its unceasing influence. Above, beneath, around, within, it is every where, and at all times present.

The distinctions to which reference has been made as appertaining to different bodies, and by which some are described as *electrics* and others *non-electrics*, are very convenient, but it must be remembered that they are not strictly philosophical. By proper arrangements, and the aid of delicately-constructed instruments, it can be shown that what are called non-electrics may be electrically excited, and hence we conclude that every substance is, in that sense, an electric, and susceptible of being excited by contact or friction with some other substance. Thus, if one of the metals, all of which are classed among non-electrics, be insulated in a particular manner, it may be

electrically excited, and the reason why it exhibits, under ordinary circumstances, no signs of that excitement is, that, being a good conductor, the electricity is conveyed away as soon as it is generated.

It is also proper to remark that the terms *conductor* and *non-conductor* apply rather to the forms or conditions of bodies, than to the combination of their elements. For example,—resinous substances, which in a solid state are non-conductors, conduct readily when melted. Glass, when cold, is a non-conductor, but becomes a conductor at a red heat. Water in its liquid and vaporous forms is a conductor, in a solid state it is a non-conductor. Silk, which, in its raw or bleached state, is a non-conductor, will sometimes become a conductor when dyed. This is partly owing perhaps to the colouring matter with which it is imbued, but chiefly, we believe, to its becoming more susceptible of hygrometrical changes. The last substance we shall mention is air, which, in common with other gaseous bodies, is a non-conductor when dry, but becomes a good conductor when highly charged with moisture. Hence it often happens, that the most carefully arranged electrical experiments yield only disappointment and vexation to the operator, through the occurrence of a change of temperature, a sudden shower of rain, or the ingress of air by a window or door incautiously left open. A warm and dry atmosphere, and especially the latter, are conditions on which the success of electrical experiments mainly depend.

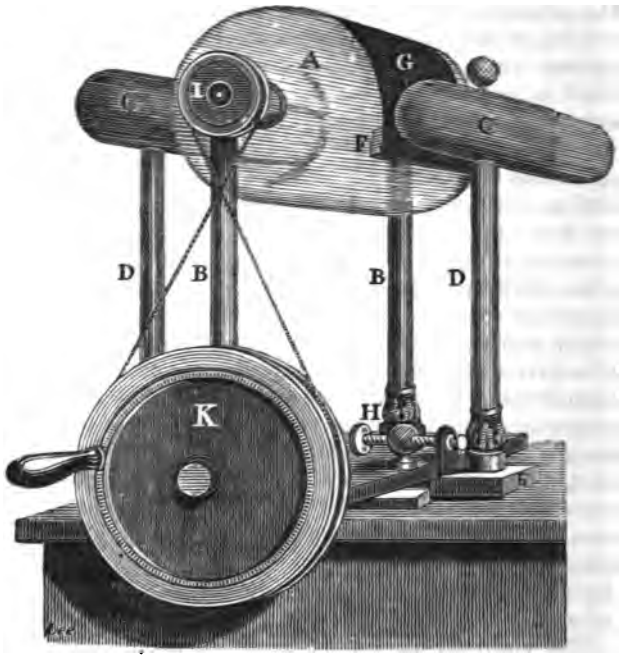
Nor must it be forgotten that the *positive* and *negative* states of electricity are determined by the forms, colours, and conditions of bodies, quite as much as their conducting or non-conducting properties. Thus smooth glass when excited by woollen cloth becomes positively electrified, but the same glass similarly treated, if it have its surface roughened, will denote the negative state. We could enumerate many other instances of this kind, but this must suffice to illustrate the principle.

As respects the precise application of the terms *positive*

and *negative*, we may observe that philosophers are divided in their views whether there be in reality two distinct kinds of electricity, or only one which exhibits itself in two different states. Much has been said in support of both theories; and as electrical phenomena can be satisfactorily explained by either, we shall offer no opinion as to which is most correct. If there be only one kind of electricity, we may suppose that when a substance exhibits what is called the positive, it possesses *more*, and when negative *less*, than its ordinary proportions. Hence when glass is rubbed with a piece of silk, some of the electricity contained in the silk is transferred to the glass, which then has *more* than its ordinary share; whilst the silk, having been deprived of part of its electricity, has *less* than its usual quantity. The equilibrium thus disturbed is speedily restored by the escape of electricity from the body which is overcharged, and the reception of it from that, or some other body, by the substance which is undercharged. By the alternate disturbance and restoration of the equilibrium which, under ordinary circumstances, exists in respect to the electrical relations of bodies it is, that all our researches in this delightful branch of science are conducted.

The electrical machines best adapted for experimental purposes are those of the cylindrical form, and of which the figure at page 334 is a representation.

These machines are made of various sizes, but one of the dimensions we are about to describe is we think most generally useful. A is a *glass cylinder* say twelve inches in diameter and twenty inches long, mounted on two glass pillars B B, which are fixed to a broad base of mahogany or other hard wood. The cylinder turns on an axis at each end (one of which is shown at I) by means of the multiplying wheel K. C C are two metal cylinders called *conductors*, about four inches in diameter, closed and rounded off at the ends. These are also placed on glass pillars D D, each of which is firmly cemented to a piece of wood E, which, moving in a groove and by

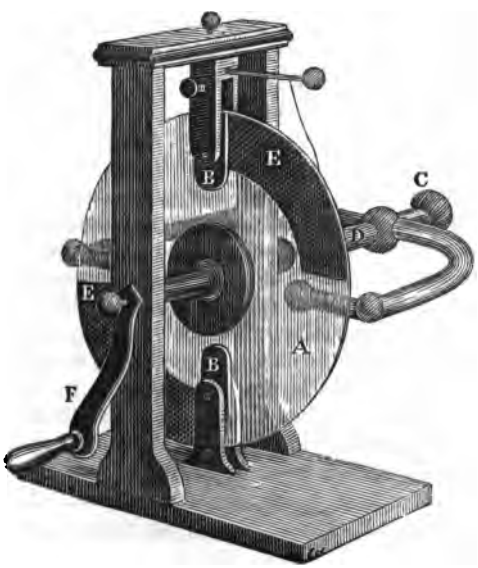


adjusting screws H, admits of their being regulated with the greatest exactness. One of the conductors has a *cushion*, or *rubber*, connected with it extending nearly the whole length of the glass cylinder, and against which it is gently and uniformly pressed by a metallic spring. To the upper part of the rubber is sewn a flap of green or black *oiled silk* G, which reaches across the surface of the cylinder to within about three-fourths of an inch of some *steel points* which project from the side of the opposite conductor. The conductor to which the cushion is attached is called the *negative*, the other the *positive*, conductor.

The machine being perfectly clean and dry, and some fresh *amalgam* spread on the rubber, it is ready for action.

The subsequent arrangements must depend on the nature of the experiments proposed to be performed. When the negative conductor, by means of a chain or wire, is made to communicate with the stand of the machine, or, what is still better, the floor of the apartment, on turning the cylinder, *positive* electricity is given off from the conductor on the opposite side. To obtain *negative* electricity the positive conductor must be made to communicate with the floor, that to which the rubber is attached being insulated, when negative electricity will be evolved from it.

The *plate machine* as shown below is more portable than those of the cylindrical form, and for some purposes it is preferable. We may especially mention the simplicity of its construction, the facility with which it may be cleaned and excited, and the length of time it continues in action. Negative electricity cannot, however, be obtained by these machines unless they are insulated in a particular manner.



A is a circular plate of glass mounted on an axis which passes through its centre, and is supported by a base and stout frame-work of mahogany. It is turned by the winch F. Two pairs of rubbers B B press the opposite sides of the plate, and to these are attached long flaps of oiled silk E E. The conductor C is provided with points similar to those in the conductor of the cylindrical machine. D is a rod of glass by which the conductor is insulated.

Section XCVII.—Electrical Apparatus.

The effects of electricity as illustrated by a good machine in the hands of a skilful operator, are exceedingly striking and beautiful. As exhibited in natural operations, and especially during a thunder-storm, they fill the mind with awe; producing, and not without reason, the most painful apprehensions of impending danger.

It is difficult, perhaps, to understand why vegetation should languish and die beneath the unmitigated heat of a cloudless sun; or why floods should carry devastation across valleys thickly-covered with corn; or earthquakes shake cities to their foundations and bury beneath the ruins their affrighted inhabitants; or the electric flash rend the oak of a hundred winters, and spread terror and death among human habitations. But if we cannot comprehend the reason for these strange visitations, we may be quite sure that they are necessary; tending equally to the general happiness and well-being of man, and the preservation of inferior animals, as the sunshine and the calm, the genial shower and the refreshing breeze.

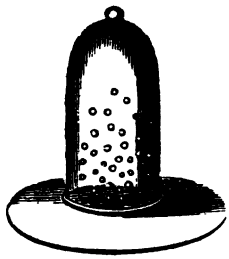
An electrical machine, when in good action, produces, at various parts of the plate, (or cylinder,) a succession of brilliant sparks which are accompanied by a peculiar crackling sound. When the conductor is attached to the machine, if the knuckle be presented to it, sparks will pass rapidly and produce a painful sensation; the pain being greater in proportion to the distance. A rounded surface of metal, as a brass ball, for instance, being held

near the conductor, in that case the spark will pass as before, but larger and more brilliant, and a tingling sensation will be felt in that part of the hand in contact with the ball. This is occasioned by the electricity in passing from a perfect, to a less perfect, conductor. Instead of a ball if we take a piece of wire with a sharp point (a common sewing-needle will do,) and hold it near the conductor, the electricity will pass silently, and the only indication of its presence will be a bright star of light at the point of the wire. However large, or powerful, an electrical machine may be, the whole of the electricity generated by it can be drawn off silently by the means just described; whence we learn, that the best method of protecting buildings against lightning is by pointed conductors fixed on the outside and in contact with the earth.

Place a person on an electrical stool (which is a stool with strong glass legs), and in communication with the conductor of the machine by means of a chain or wire held in the hand. On turning the machine the person on the stool will become charged with electricity, and sparks may be received from various parts of his body in the same manner as from the machine itself; and if he present his knuckle near to the surface of a small quantity of spirit of wine, held by another person in a metal spoon, the spirit will be inflamed.

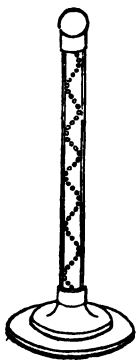
If the figure here represented, and which is a block of wood carved in the form of a human head and covered with long hair, be placed on the conductor, the hairs separate and stand on end; affording an instance of repulsion in consequence of each hair being charged with the same kind, or being in the same state, of electricity. The same thing happens when a person stands

on the insulating stool, as already described. On bringing a pointed wire near the head the hairs will instantly fall, or, uniting at their extremities, may be made to move in any required direction.



A few pith balls under a glass vessel of the shape here shown, or a common tumbler will answer every purpose, furnish an amusing example of the non-conducting properties of glass, of attraction and repulsion, and of the constant effort in an overcharged body to get rid of its redundant electricity. The glass being electrified on the inside by means of a wire attached to the conductor, it must be placed over the pith balls, which will leap to the top and from side to side of the glass for several minutes. This is the effect of alternate attraction and repulsion between the glass and the balls; the latter being engaged in carrying the electricity from the glass to the table on which it stands.

A glass tube with small discs of tin-foil pasted very near to, but not in contact with, each other, is placed within another tube and the ends fitted with brass caps; or only one end is so finished, and, as in the adjoining figure, the other is affixed to a stand, and constitutes a favourite piece of apparatus with young people. Sometimes two flat pieces of glass are used, and tin-foil so arranged on one piece as to form a luminous word by passing a succession of electric sparks over the glass. In either case the effect is the same, and results from the electricity becoming visible in passing through the small space between each piece of metal —for if the latter was continuous the electricity would pass unobserved.



When referring to the opposite states of

electricity, as induced by the friction of two bodies which are easily excited, we mentioned that this was the case not only with two different substances, but with different sides of the same substance. This is illustrated in the *Leyden jar*, which consists of a thin and perfectly sound glass vessel covered on both sides to within a few inches of the top with tin-foil, as here represented, and surmounted by a brass ball which communicates with the inside of the jar. If we hold the brass ball near the conductor of the machine, electricity will pass from the latter to the inside of the jar, and in a very short time it will be fully charged; and if it be not removed from the conductor the electricity will spontaneously discharge itself with a sharp report, not unfrequently fracturing, and rendering useless, the jar. But supposing the jar to be charged with electricity, if we make the inside surface to communicate with the outside, a report will ensue, and the jar will no longer exhibit electric excitement on either side.

The Leyden jar is easily managed by a jointed discharger (see the fig.), which consists of two bent brass wires *b*, terminated with balls about three-fourths of an inch in diameter, and moving on a joint to which is attached a glass handle.

The two opposite states of electricity, as induced in different bodies, we referred to in speaking of glass when rubbed with silk, and sealing-wax when rubbed either with silk or woollen. The same thing happens in the friction of the electrical machine, the rubber being negatively, and the glass positively, electrified, at the moment when they are operating on each other. But in the Leyden jar the opposite kinds or states of electricity are induced, and, as some would suppose, through the substance of the glass;

for whilst the inside of the jar is made positively electrical, the outside becomes negatively electrical by the self-same process. Let us, however, investigate this matter more closely, and we shall find that glass is almost entirely impermeable to electricity; and that the charge which accumulates on the outside of a jar, whilst the inside is in communication with the machine, depends on a very simple arrangement, namely, that the outside of the jar be connected, in some way or other, with the earth; that is, it must not be insulated.

If a jar *b*, mounted on an insulating stand *a*, have its knob placed near the conductor, and the air in the room be dry, it will be found impossible to charge the jar whilst so situated. Now let a similar sized jar *c* be placed at the same distance from the knob projecting from the insulating stand, as that of the jar *b* is from the conductor. On putting the machine in action it will be found, that for every spark which passes from the conductor to the inside of the jar *b*, a corresponding spark will pass from the outside of *b* to the inside of *c*, and after a few turns of the machine they will both be found to be equally and similarly charged. Hence we perceive that when electricity accumulates on one side of a glass vessel, a corresponding quantity is driven off from the opposite side; and this is a condition essentially connected with all electrical phenomena.

It is proper to explain the use of tin-foil as a coating for glass in electrical experiments. The electricity diffuses itself over the surface of the glass, and is not in

any way affected by the proximity of the metal; but as glass is a non-conductor, the electricity could not be separated from it at any required moment without the aid of the metallic coating; which being a good conductor enables us, in an instant, to discharge all the electricity which has accumulated underneath it, on the surface of the glass, however extensive that surface may be. When two or more Leyden jars communicate with each other, they are called a *battery*, and if properly connected they may be charged simultaneously; and when they have received as much electricity as they will contain, or as may be required, the whole of it may be dispersed with the velocity of lightning. Thus the Leyden jar is the most useful piece of apparatus we have. By its means we determine with accuracy the quantity, or rather the tension of electricity, required for any particular purpose; and hence gunpowder and other combustibles may be inflamed, metals heated or dissolved, electric shocks communicated to the human frame for the relief or cure of certain diseases, and a variety of other experiments performed; tending to enlarge our acquaintance with the habits and properties of this all-pervading agent, at the same time that we learn the best means of defence against its destructive effects.

Section XCVIII. Galvanism, or Voltaic Electricity.

Although we have spoken only of electricity as developed by the friction of certain substances, in which it is more easily excited than in others, it is proper to observe that the electral relations of all bodies are constantly changing; being disturbed by what may appear extremely slight and insufficient causes. We believe it impossible to produce any material change in the form, colour, temperature, and general condition of bodies without affecting their electrical equilibrium. By suitable instruments it can be shown that suddenly tearing asunder, crushing, or heating

of solid bodies; evaporating of liquids; and condensing the vapours which arise from those liquids, are all distinct sources of electrical phenomena; and hence we learn that electricity performs an important part in all the operations which are going on in the earth, the ocean, and the atmosphere.

When a piece of silver, say a half-a-crown, for instance, is placed *on* the tongue, and a piece of zinc about the same size *underneath* it, so long as the metals remain asunder no effect is produced, but on their edges being brought in contact, a peculiar pricking sensation is experienced in the tongue, accompanied by an unpleasant metallic taste. This is called *Galvanism* or *Voltaic Electricity*, and refers to that species of electricity which results from the contact of two certain substances with or without the intervention of any other—but especially to that which is an attendant on chemical action.

The first step in this branch of science was made by Galvani, a physician of Bologna, about the year 1790, who accidentally discovered that a small quantity of electricity being passed through the nerves of the hind legs of a recently-killed frog produced spasmodic contractions of the muscles, resembling those exhibited in the living animal. Moreover, it was found that these remarkable effects could be produced without the aid of an electrical machine, nothing more being necessary than two dissimilar metals, as silver and zinc, properly disposed; the convulsions occurring as often as they were brought in contact, and not in frogs only, but in other animals several hours after they were dead.

The discovery immediately attracted attention, and excited a spirit of anxious inquiry wherever it became known. Galvani concluded that the phenomena to which we have referred were dependent on *animal* electricity, and that the nerves and muscles being in opposite states of electricity the spasms were produced by the neutralization of these opposing currents, through the interposition of the metallic conductors.

This opinion was shown to be erroneous by Galvani's countryman, Volta, who demonstrated that the metals were the true sources of electrical excitation; and to the last-mentioned philosopher we are indebted for some very valuable suggestions in this newly-discovered science. Hence it is that the terms *galvanism* and *voltaism* are both used to distinguish this from common electricity; but more frequently it is now described as *voltaic electricity*.

Our space will not admit of entering largely upon this interesting, and, as it has since become, highly important department of experimental science. All that we can promise is a hasty glance at a few familiar experiments, and an explanation of the apparatus employed in conducting them.

The following figure represents the legs of a frog as prepared for galvanic illustration; in which the skin being removed, the crural nerves *a a*, are found by separating the muscles. *b* is a silver, or clean copper, wire placed under both nerves in order to insure metallic contact. If the muscles be now placed in contact with a piece of zinc, (a piece of zinc-foil may be wrapped round them,) and a communication effected with the metal in contact with the nerves, contractions will ensue as often as the contact is broken and renewed.

Recent experiments have greatly enlarged our knowledge of animal electricity. Although Galvani was wrong in concluding that the spasmodic contractions of the muscles of a frog, as produced by him, were due to an

electrical action in the muscles or nerves, and which manifested itself independently of metallic excitation; yet he was perfectly right in believing and asserting that electrical currents did exist, and could be developed solely by the muscles of the animal. He possessed not the requisite knowledge for proving what he affirmed. He was right in principle, but wrong in practice. The wonder is that he knew and did so much, with what must have been, in his day, such startling phenomena.

In his endeavours to disprove that which Galvani had rather guessed at than illustrated, Volta made many valuable discoveries in this branch of natural science. On the subject of animal electricity, however, he was as much in error as his contemporary. We are indebted to both of them. They deserve to be held in remembrance. Probably we owe as much to their differences as we do to their points of agreement.

The existence of what is termed 'the frog current,' has now been satisfactorily established. It can readily be shown that, when properly treated, the muscles of a recently-killed frog influence a magnetic needle precisely in the same manner as a voltaic arrangement of dissimilar metals. Nor is this all. The long-disputed question as to the power possessed by man of evolving electricity is not left to conjecture. By means of an extremely delicate instrument (a galvanometer of a peculiar construction, see p. 354) an electrical current is proved to exist; the needle being deflected in opposite directions, by the alternate contraction and relaxation of the muscles in each arm of the operator.

Other and still more remarkable indications of electrical, or more properly, perhaps, electro-magnetic phenomena have lately been noticed in connexion with the human body. Care, and skill, and patience, are required for such investigations. With these qualifications, aided by suitable instruments, it is hoped that we shall, eventually, know a great deal more about the electrical conditions of health and disease.

We have mentioned that electrical excitement results from the mere contact of dissimilar metals. To determine that fact, a delicate instrument is required, called a gold-leaf electrometer. Here is a sketch of one:—*a* is a cylindrical glass vessel inverted on a mahogany stand at *b*, (not shown in the fig.) *c*, is a cover of dry wood, varnished, and with a slit in it, to which glass tubes, *d d*, are adapted in such a manner that they may slide backwards and forwards as may be required. To these tubes are fitted brass wires, with a slip of gold-leaf attached to the ends which project into the glass vessel.

If a large plate of metal be placed on the top of the instrument just described, so as to be in contact with both the wires, *d d*, (which must be placed very near to each other) and zinc filings be passed through a copper sieve (held by the operator by a glass handle) so as to fall upon the plate, the gold leaves will immediately diverge; the electricity thus excited being *positive* in the electrometer and *negative* in the sieve. By using copper filings and a zinc sieve, the effect will be exactly the reverse.

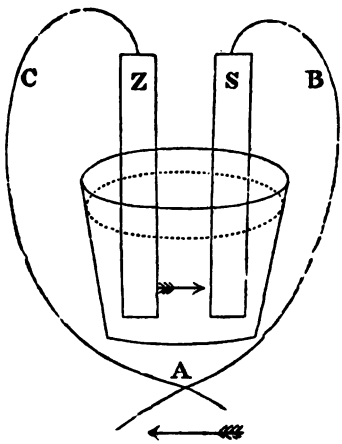
The electrical changes induced by chemical action are still more apparent.

If we put a piece of clean plate iron and a piece of silver, a spoon, for instance, into a weak solution of sulphate of copper (*blue vitriol*), the iron will speedily become coated with metallic copper; but the silver will remain unaffected. If we now place the iron and silver in contact with each other, the latter will instantly be covered with copper like the iron.

But in order that we obtain decisive indications of an electrical current passing between different metals, it is necessary to arrange them in what are called galvanic circles, and these are of two kinds, simple and compound. A simple galvanic circle consists of two different metals

partially immersed in a vessel containing water, but most commonly diluted acid; a communication being made between the two metals either by direct contact or by means of wires firmly attached to each plate. As it is found that the greatest amount of electrical excitation exists between those metals, one of which is the *least*, and the other the *most*, readily oxidized, that is, acted upon by acids, for small experiments *silver* and *zinc* are employed; but where a great number of plates, or a large surface of metal, is required, silver is too expensive, and *copper* and *zinc* are found to answer exceedingly well.

In a simple circle (see the fig.,) two plates, say one of zinc, z, and one of silver, s, are partly immersed in dilute sulphuric acid. Previous to the wires, B C, being brought in contact at their extremities, A, the zinc only will be acted upon; but the moment the ends of the wires touch each other the silver will become active. This will be evident from the bubbles of gas arising from it, as well as from the zinc, and it may also be shown by the divergence of the leaves of the electrometer. In this, and indeed every other galvanic arrangement, the electrical relations of metals are found to be, that the least oxidizable are negative with respect to those most oxidizable.



In the figure therefore the zinc is positive with respect to the silver; so that a current of electricity passes, in the direction denoted by the arrows, from the zinc to the acid and water, thence to the silver through the wires, B C, whilst they are united at A, and back to the zinc

again. When the extremities of the wires are in contact, the circuit is said to be 'closed;' when separated, it is described as an 'open' circuit.

The effects of voltaic electricity depend on two conditions, namely, *quantity* and *tension*. For some purposes of illustration a great quantity, but of feeble tension, is necessary; for others a small quantity, but of high tension, is required. In the former case, it is usual to employ one plate of each kind of metal (or if more than one is used they are so arranged as to act the part of one only), with a large surface exposed to the fluid, the strength of which, in reference to its oxidizing effects on one of the metals, determines the energy of the chemical, or in other words, the electrical action. When a large quantity of electricity is passing through the connecting wires, or *poles*, of a simple galvanic circle, if a metallic wire, a piece of fine steel wire for example, form part of the circuit, it will be heated red-hot, or melted; effects which depend on the size and length of the wire and the quantity of electricity transmitted through it. In like manner a platinum wire might be heated or fused, as may other metals according to their relative conducting properties.

At page 312 we have referred to the intense brilliancy of the light which accompanies a current of voltaic electricity when passing between charcoal points. This experiment can be shown with a simple circle, but generally speaking it is more convenient to do it with electricity of considerable tension. The following figure will convey a correct idea of the method of arranging the apparatus;

which consists of a pair of metallic forceps, the jaws of which are pressed together on the pieces of charcoal

(pointed something like a lead-pencil) by a sliding ring, and the other extremities of the forceps are in direct contact with the poles of the galvanic apparatus.

The chemical effects of voltaic electricity are so numerous, and they occupy so large a space among the details of the science, that we must refer the reader to those works which contain a full account of them.

We may just mention, however, that, as a *chemical* agent, electricity of *tension* is necessary, which is obtained by the compound circle, or *battery*, as it is usually called; consisting of a greater or less number of plates arranged in pairs, according to the effects it may be desirable to illustrate. For some purposes a series of small plates, say only two inches square, will be sufficient; for others, a larger size, as four or six inches square, is more convenient; and the series may consist of any number, from 20 to 200 pairs. There are various modes of fitting up a voltaic battery. In some cases the plates are fixed in a frame-work of wood so as to form cells between each pair for the reception of the exciting liquid; in others a porcelain or glass vessel divided into cells is used, into which diluted acid is placed, and the plates introduced as occasion requires. The latter is the most convenient, as it is also the most economical, form.

Very great improvements have lately been made in voltaic arrangements, which facilitate the manipulations, while they save the trouble and expense of frequently changing and replenishing with acid. This is accomplished by means of what is termed a *sustaining battery*—of which the following is a description:—Having obtained an earthen-vessel (say a jar such as is used for preserves) capable of containing about two quarts, let there be fitted to it a cylinder of zinc, open at the top and bottom, and a similar cylinder of copper, but about one inch less in diameter than the zinc. To the outside of the copper cylinder a stout bladder must be tied so as completely to envelope and form a bottom to it; a short wire soldered to the upper edge of each cylinder, and terminating with

small binding screws, completes the arrangements. Several of these jars, say from 10 to 100, may be used with greater effect than three times the number of ordinary-sized plates; and with this additional advantage, that whereas the common battery can be kept in action only for a few minutes at a time, when the energy is great; the sustaining battery, as its name implies, will continue in full activity for many successive hours. This increase, as well as prolongation, of power by the arrangement just described, is also effected without the direct application of acids. The space between the outside of the bladder, which envelopes the copper cylinder and the zinc, being filled with a saturated solution of chloride of sodium (*common salt*), and the interior of the bladder with a similar solution of sulphate of copper (*blue vitriol*), electrical excitement immediately commences and is carried on through the bladder until the energy of the last-mentioned liquid is expended.

The various purposes, in the useful arts and manufactures, to which voltaic electricity is now applied, has originated many new forms of apparatus. It would be impossible, within any reasonable space, to give an account even of the forms and materials used in constructing single-cell and compound battery arrangements. The sustaining battery just described was invented by the late PROFESSOR DANIELL. It has in part been superseded by the batteries of GROVE and SMEE, which enjoy a world-wide reputation; and, according to the objects to be attained by them, they seem to combine the most essential properties of power, durability, and economy.

Smee's battery is especially applicable in electro-metallurgy—a beautiful process, out of which has grown, what is better known in commerce and the arts, as electro-plating.

Section XCIX. Magnetism.

It has been known, from a very remote period, that a certain ore of iron, called by mineralogists *magnetic iron ore*, possesses the property of attracting iron, and of imparting to it the same power, in this respect, which it exhibits itself. Masses of this ore are found in various parts of the world; but the magnetic influence is so easily communicated, and so long retained, by bars of steel properly prepared, that the natural magnet, or *loadstone*, is scarcely ever used.

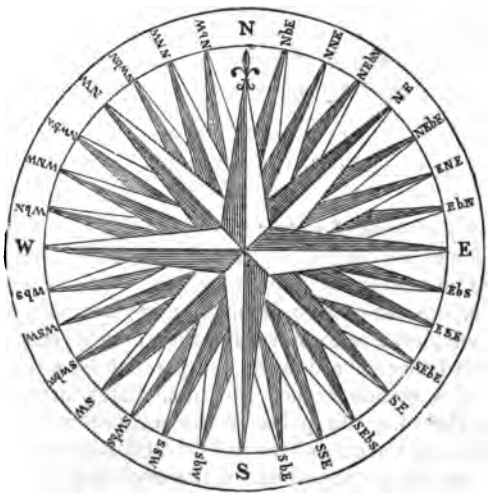
When a bar of steel has the magnetic property imparted to it, whether by contact, or rather friction, with a piece of ore, or a similarly magnetized bar, if it be freely suspended by its centre, one of its ends will point towards the north. This is termed *polarity;* and that end which points to the north, is usually called the *north pole*, and that which points in an opposite direction, the *south pole*. There is a very striking analogy between the magnetic and electric properties of bodies; for as those which are in similar states of electrical excitement repel, and those in dissimilar states attract, so it is found that two north poles of a magnet repel, but a north and a south pole attract each other.

In this country a magnetized bar, or, as it is termed, *a magnetic needle*, does not point exactly north and south, but the north pole of the needle takes a direction considerably to the *west* of true north. This is called the *variation* of the needle, and in obedience to a law which we do not understand, it is constantly changing. It also varies at different parts of the globe, and at different periods of the day or night. In 1657, the needle in this country pointed true north. Previous to that period, its variation had been on the *east* side of north; but afterwards it took a westerly direction. In 1814, it attained its greatest variation, and from that time till the present

it has been slowly returning, and in about 130 years it will, perhaps, again reach the line of no variation.

When a bar of steel, properly prepared and very accurately balanced on its centre, previous to its being magnetized, has the magnetic influence communicated to it, that end which has a northerly direction will be observed to incline downwards, thus appearing heavier than the opposite end. We need hardly say, that in reality there is no difference in their weight; the descent of the needle, which is termed the *dip*, being occasioned by the attraction subsisting between it and the earth.

We have already referred (page 36) to magnetism as guiding the mariner across the ocean. The *mariner's compass*, of which the following is a representation,



consists of a bar of steel rendered magnetic, and poised on its centre, and to its upper side is attached a card, with the four cardinal, and twenty-eight intermediate, points, marked as in the figure. The whole is inclosed

in a box with a covering of glass, and the box itself is suspended on gimbals, to prevent the compass-card from being thrown off its bearing by the motion of the ship.

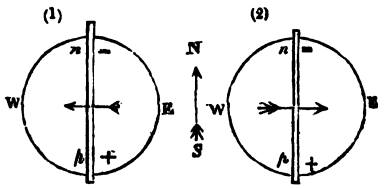
Iron is not the only metal susceptible of magnetic influence, but on others the effect is feeble and transient, and hence they are never applied to any practical purpose. Nor must it be forgotten that *soft* iron soon parts with its magnetic properties; hence steel is always employed for artificial magnets, as, by proper precautions, they retain their energy for many years, and it is rather increased than diminished, by their being used in communicating it to others.

Artificial magnets lose their directive property by being heated to redness; violent concussions, or lightning, will also destroy it; but in some cases the effect is only a reversal of the poles. So, in like manner, will sharp blows, change of temperature, and lightning communicate magnetic properties to iron or steel.

Section C. Electro-Magnetism.

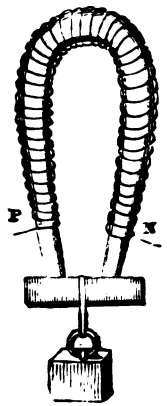
When a current of voltaic electricity is traversing a wire used for connecting the poles of a battery, if a magnetic needle be brought near the wire, it will be attracted by it and thrown out of its ordinary line of magnetic direction. A needle, left free to move, and then take its natural position, on being placed over, and parallel to, a connecting wire of a voltaic circuit, will immediately arrange itself *across* the wire, the poles of the magnet being at right angles with the axis of the wire. The same will happen if the needle be placed under the wire, but in that case the poles of the magnet will point in a direction opposite to that in the first-mentioned experiment. The following diagram will explain this more fully. Let *p n* be a conducting wire (1) traversed by an electric current in the direction s N, in which case the north pole of the

magnetic needle placed *above* the wire, will be deflected towards the *west* (W), and in the other case (2) when placed *below* it the same pole will be deflected towards the *east* (E).



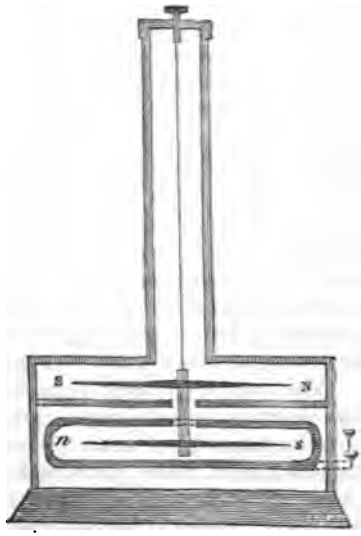
These phenomena, which have received the name of *Electro Magnetic*, were first noticed in 1819, by Professor Œrsted, of Copenhagen. Within the last few years electro-magnetism has been cultivated with a degree of success almost unexampled in the history of science, and it is now treated of as a distinct branch of experimental philosophy. Its effects are the result of *electricity in motion*, irrespectively of tension, and are proportionate to the quantity present, and not to its velocity. For experimental purposes the voltaic arrangements are those of the simple battery; and the magnitude and success of the operations depending on the extent of metallic surface, and the perfect contact of the conductors.

But the same influence which affects the magnetic needle, in the way we have described, also communicates magnetism to soft iron; and hence, if a bar of that metal be surrounded with a copper wire, (care being taken that it do not actually touch the iron,) through which a current of voltaic electricity is passing, the bar becomes a powerful magnet, and will continue so as long as contact with the battery is preserved. On breaking contact, the magnetism of the bar disappears, but it may be renewed again at the pleasure of the operator. The most convenient form for a temporary magnet is that shown in the following sketch, (p. 354). It is called a *horse-shoe* magnet, and is surrounded with copper wire, covered with cotton, which prevents the wire from forming metallic contact with the iron or with itself in any of its convolutions. P and N are the ends



of the wire, which must be placed in perfect contact with each plate of the voltaic battery. The wire which surrounds the bar of iron is called the *armature*. A single coil is not sufficient to produce so powerful an effect, as six or eight distinct lengths of wire, which must all be coiled in the same direction, and their extremities soldered to larger wires, called the poles. Thus fitted up, a bar of iron, say one inch in diameter and twelve to fourteen inches long, may be rendered sufficiently powerful, as a magnet, to sustain from 150 to 200 lbs.

By means of electro-magnetism we are enabled to detect, and to estimate with considerable nicety, very feeble currents of electricity; such as under ordinary circumstances would pass wholly unnoticed, or be recognised only by their effects after the lapse of many months or years. A useful instrument employed for this purpose is called a *Galvanometer*, (see the annexed figure), which consists of two delicately-suspended needles, the north pole of one being opposite to the south pole of the other. This is called an *astatic* arrange-



ment, and is intended to neutralize terrestrial (that is, the earth's) magnetism. Around the lower needle, is coiled several yards of fine copper wire, covered with silk, to insure perfect insulation. The ends of the wire terminate at two small cups, to contain mercury, and by means of which contact is made with the metals, or other substances to be examined. A semicircular arc, divided into 180°, 90° each way, beginning in the middle, is placed just underneath the upper needle, so as to enable the observer to read off the amount of deflection. The needles are suspended by a filament of glass, or still better, of unspun silk. The sensitiveness, if we may employ the term, of this instrument to electrical excitement, the smallest conceivable portion of which is multiplied by its transmission through the copper wire, would scarcely be credited by those who are not familiarized with investigations of this kind. A piece of silver and zinc less than the hundredth of an inch in diameter, placed in a vessel containing spring water, ten inches distant from each other, on being made to communicate with the poles of the galvanometer, will cause the needle to deflect from 30° to 50°. From this experiment, we may learn how it is that where two dissimilar metals are in contact, oxidation proceeds more rapidly than at any other part; familiar examples of which are furnished by the fastening of iron railings with lead, and of lead and copper gas-pipes with iron. In both instances galvanic action ensues, and is greatly promoted by moisture, especially in the vicinity of the sea.

If a piece of platinum, and a similar piece of iron, wire, say about ten inches long, are slightly twisted together, and their ends immersed in the mercury-cups of the galvanometer, whilst their opposite ends are held in the flame of a spirit-lamp, the needle will be deflected. This is an instance of *Thermo-Electricity*, and depends on the difference in the relation of the two metals with respect to electricity induced by heat.

When a steel magnet is made to revolve very near

to a soft iron armature; the latter being covered with copper wire, in the same manner as an electro-magnet, the iron becomes highly electrical by induction, and exhibits all the properties common to a voltaic battery. This is termed *Magneto-Electricity*, and by its means we are enabled to perform all the illustrative experiments which at one time were thought to belong exclusively to voltaic arrangements. The identity of electricity and magnetism is thus clearly demonstrated; the boundaries of knowledge are enlarged, doubts are removed, and that which was once dark and mysterious is enlightened as by a sunbeam.

Section CI.—The Electric Telegraph.

We are living amidst so many wonders, and they have succeeded each other with such extraordinary rapidity, that we have not had time to examine any one of them as it deserves. Things once considered to be the dreams of enthusiasts are now known to be realities, and theories which used to be thought fanciful, whilst acknowledged to be beautiful, have long since taken their places amongst the hard practices of every-day life. Motives and impulses, as various and as dissimilar as the aims and objects of projectors, have kept hands and heads busily employed. Light has been brought up from the coal-mine, and laid at our doors, to be used as it is required. Oceans and empires are traversed with the fleetness of the wind; the time it occupies being reckoned by hours and minutes, instead of weeks and days. Science and art have united their skill and their energies, and, by the aid of machinery, have made Britain a workshop for the world.

But the Telegraph is the greatest of all modern achievements. The lightning of the heavens has been made obedient as a child, and tractable as a well-trained servant. Swift to fulfil our commands, it travels by day and night, conveying intelligence, asking questions, and

giving prompt replies, between places hundreds of miles apart; and, although the agent is invisible, and its movements unheard, it makes itself as well understood as if it spoke audibly, and shone with the radiance of sunlight. Performing one-half of its journey by the road we prepare for it, the other half is traversed by a path it chooses for itself. In one direction it permits the wire to direct its course; in the other, it rushes back without a guide, but with unerring certainty, through the earth. Nor does the ocean present any impediments to this fleet messenger. Exploring its mysterious caverns, it dives down amongst weeds, and shells, and fishes innumerable; and, far beyond the reach of storms, and waves, and breakers, it passes along the wires, which are laid for its accommodation, from shore to shore. Thus does the electric wire connect city with city and kingdom with kingdom; carrying 'thoughts which breathe and words which burn' by 'a path which the vulture's eye hath not seen.'

In the space we here can occupy, it is impossible to give anything like a history of the telegraph, or to describe the various forms of apparatus employed in its manipulations. Unlike many other great and useful inventions, it has not been made up of bit-by-bit improvements at distant periods of time. The men who commenced it have seen it, in a practical sense, perfected. It has been a work of progressive improvements; but they have come so quickly one upon another, that it is difficult to say which is most wonderful, the telegraph itself, or the rapidity with which it has passed through its several stages from suggestion to completion. The first rough thought, the first series of experiments, had scarcely been talked about, when we heard that hundreds of miles of wires had been fixed, and that all sorts of messages, from inquiries about a missing umbrella, to those affecting the destinies of nations, were passing quietly along them.

The principle of action in the telegraph is electro-

magnetism (p. 352), causing the deflection of a magnetized needle by the passage of a voltaic current through the wires which surround it. Let it be remembered that the needle is not in contact with any of the telegraph wires, nor does the electricity pass through it. The motions of the needle, in opposite directions, are produced by the electric *aura*, or atmosphere, in which it is enveloped. We have already described (p. 353) the power possessed by a voltaic current, traversing a wire, to turn a magnetic needle out of its line of direction, and so cause it to arrange itself at right angles to the axis of the wire. This is exactly what is done by the telegraph wires. The current in a single wire is sufficient to affect a needle; but by using a number of convolutions, the force (intensity) is greatly increased. Telegraph needles are therefore surrounded by helices, or coils, consisting of several hundred feet of fine copper wire covered with cotton or silk. The energy of the electric aura is thus multiplied; and, according as it passes above or below, or, in other words, in one or the other direction around the needle, so does it compel it to point to the right, or the left, of the observer. The flitting from side to side of the needle is in reality its deflection eastward and westward; its proper line of direction being north and south. Although differently arranged, the telegraph needle is, in its essential properties, a galvanometer (p. 354). For greater convenience in reading off indications, and obtaining quicker movements, the needle is fixed vertically, instead of horizontally; and mechanical contrivances are also resorted to which facilitate the operations.

The motions of the needles right and left, and the number of oscillations (beats) in each direction, indicate letters, figures, words, stops, and signals, according to previous agreement. By these means, two or more persons communicate with each other, without regard to distance; and with the same degree of accuracy, and almost as great rapidity, as if they were talking face to

face. Most truly has it been said by one well experienced in such matters—'I can never see a signal transmitted without being lost in admiration at this wondrous creation,—which moves we know not how, and acts we know not why, but which is conveying our thoughts far away so truthfully that we, at times, almost forget that it is mere wood and metal before us, and, absorbed in what is passing, imagine the telegraph instrument endowed with vitality, and actually itself holding converse with us.'*

We have already hinted, although we have not fully explained, that the electric current passes only in one direction, from station to station, along the wires; the other half of the circuit being completed, in a way wholly unknown to us, through the earth. Distance has nothing to do with this part of the arrangements. Never mind the length or number of wires—if there be sufficient battery-power—the earth does its work with greater certainty and promptitude than the wires themselves. The current passed through any particular wire, say twenty or fifty miles long, will find its way back, in an instant, to the end of that same wire, whatever the nature of the soil, or the apparent impediments interposed, as buildings, bridges, rivers, or the ocean itself. This is not sufficiently understood. We are so accustomed to think, and speak, of the telegraph as a thing in daily use, that some of its most wonderful properties pass unnoticed, or perhaps, what is more likely, they are almost entirely unknown.

Already have we a net-work of wires for conveying intelligence—spreading itself in all directions in this country. By those recently laid across the channel, between Dover and Calais, many thousands of miles on the continent are, in effect, united to our own. Ireland, by similar means, has also been brought within speaking-

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* *Electric Telegraph Manipulation*, by C. V. WALKER.

distance. The sphere of telegraphy is daily enlarging. In America, the wires exceed 27,000 miles in length, and several other lines have been projected and are in progress. The day is probably not far off when, stretching themselves westward from Ireland, these magical wires will annihilate the distance across the Atlantic. Before that is accomplished, by an easier and cheaper route eastward, England may be connected with her boundless possessions in India; and thence, far beyond, with the scenes, not of golden dreams, but of gold in its fullest realization, in our justly-famed Australian colonies.

The telegraph wires perform other, and very important, duties besides those we have just mentioned, and which require neither thoughts, nor eyes, nor hands for executing them properly. For the transmission of Greenwich mean time throughout the kingdom, wires have been laid down to the Royal Observatory, and connected there with a clock, which, by very simple mechanism, is made to give the time-signals automatically. The few preparations required, in giving due effect to these signals, the clock itself makes without being watched or assisted. The instant of noon, or any other hour that may be desired, is made known to observers by the falling of a ball. This has for some time been in operation at Greenwich, for the benefit of the shipping in the Thames. The results are so satisfactory, that it is now extended to the west parts of London; a similar apparatus having been erected in the Strand. Before long it is probable that similar arrangements will be made for telegraphing time to conspicuous parts of the coast; so that outward-bound ships may set, or verify, their chronometers up to the latest moment.

At the principal telegraph stations, the time can be simultaneously signalled by a single deflection of the needle. This being watched by the clerks, may be repeated by hand, for the benefit of intermediate and branch stations, in the fractional part of a second.

Thus are we reminded that electricity is no longer a

series of brilliant experiments adapted only for the lecture-table. We have set it to work. Already has it done wonders—not a hundredth part of which can here be described.

Section CII.—The Stereoscope.

It is fourteen years since Mr. Wheatstone first gave publicity to his views, on what he termed 'some previously unobserved phenomena of binocular vision,' that is, sight with two eyes. An instrument he had invented was at the same time described; by means of which two separate diagrams, representing different perspective views of the same object, could be made, when viewed in a particular way, so to unite as to form only one figure, having the appearance of a perfect solid. Hence the name of the instrument, which is compounded of two Greek words, signifying *to see a solid.*

Like many other ingenious, and in reality valuable, inventions, the Stereoscope, when first made known, attracted but little attention. This was, probably, owing to its being then considered more curious than useful; or it might have been in consequence of the principle of the instrument being very imperfectly understood, and the difficulties attending its construction. We think it still more likely that the discoveries and rapid advances in the art of Photography, occurring about the same time, drew off attention from Mr. Wheatstone's invention. And no wonder if it did so; the discoveries of Niepcé, Talbot, and Daguerre being justly considered as among some of the most wonderful applications of optical and chemical knowledge which the world had ever witnessed.

The Stereoscope was laid aside; but not entirely forgotten. Even by its inventor its principle appears to have been but superficially investigated; whilst it was, probably, never suspected that the discovery was not new. Attention was no sooner directed to the phenomena, which had thus been so happily illustrated, than it was

found that the subject had been treated of, and with a remarkable degree of accuracy, by writers on optics more than two hundred years ago.

To Mr. Wheatstone is due the merit of having first devised the means of practically illustrating the principle of binocular vision. To Sir David Brewster we are indebted for a truly philosophical explanation of its theoretical principles; which he has shown are as much dependent on the physical construction of the eye, and as much a part of its duty, when in a normal and healthful condition, as any of the ordinary processes by which external objects are seen and judged of in the daily business of life.

In its earliest forms the Stereoscope consisted of a box containing two plane mirrors, about four inches square, fixed at right angles to each other. (Fig. 1.) The bino-

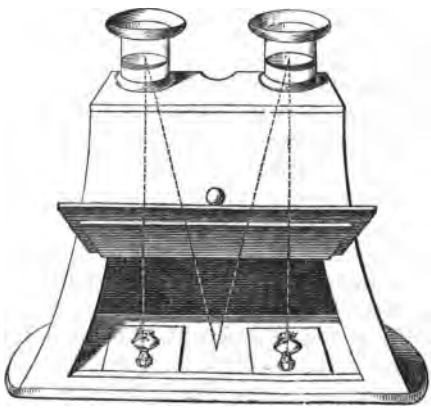
FIG. 1.

a

cular pictures were so placed, that each of them should be opposite its corresponding mirror, the reflected images being brought exactly to the centre of the box between the eyes of the observer. There the two figures united and presented an apparently solid substance; so unlike the mere surface pictures that it seemed incredible the laws of optics could be alone concerned in converting one into the other.

" Combining theory with practice, Sir David Brewster very soon simplified and improved upon Mr. Wheatstone's apparatus. The most popular form of the instrument is the invention of Sir David. This is called the *Lenticular* Stereoscope, that is, formed, or constructed, by means of a *lens*. (Fig. 2.) We will refer to it more particularly by-and-by; observing as we pass along, that it was first made at Dundee, then taken up in earnest by an eminent philosophical instrument maker in Paris, whence it found its way back to this country, at the Exhibition in 1851; and since then it has been made in London, in almost every variety of material, and sold at prices from a few shillings to as many pounds.

FIG. 2.



b

It is not an easy matter to describe the Stereoscope. Assisted by diagrams, the difficulties are not entirely removed. Even the complete instrument, with its appropriate pictures, is in the hands of many persons little else than a puzzle; and if they express approval or surprise, it seems rather by way of compliment or

custom, than from a just appreciation of the effects produced.

Let us try to explain, what might not improperly be termed, the optical illusion of the Stereoscope; that is, the method by which two dissimilar pictures, drawn on flat surfaces, and placed several inches apart, may be made, when viewed with both eyes, perfectly to coalesce and to present the appearance of only one figure; not, however, any longer a flat surface, but raised, or depressed, in its proper proportions, so as not to be distinguishable from a solid.

If we take a piece of card-board, about nine inches square, and fold it like a book, then set it on one end, with the folded edge towards the observer, the sides being very slightly separated, we shall be looking at what might be considered the thin end of a wedge. Place it at a convenient distance from, and on a level with, the eyes, and so adjust it, that each eye shall be able to see the sides of the card-board in equal proportions. Continue to look steadily at the object for a few seconds, and then shut each eye alternately; when it will be noticed, that a smaller portion of the left side of the wedge comes into view with the left eye shut, and *vice versâ*, than when both eyes are open. Try another experiment. To a fixed point, about two feet from the inside of the window of a room, attach a thread, with a weight at the bottom, to make it answer the purpose of a plumb-line. Look steadily at the thread with both eyes, and get it exactly in line with one of the upright bars of the sash. Without moving the head, direct the eyes towards the sash-bar, and *two* threads will be seen—one in its former position, and another at the right side of it. Repeat the experiment, and when the thread is again in line with the sash-bar, shut the left eye, and the thread will appear to change its position several inches to the right side of the bar. Again, adjust it with the right eye only, then shut that eye, and look at it only with the left—the thread will retain its position. Do the same thing with

the left eye, and then shut the right, and the thread will change its position as before.* The distance to which the thread appears to move depends on the distance at which the observer stands from the window. Look at an object out of doors, as the angle, or window-frame, of a building, and try the experiments just described, and the plumb-line will appear to move fifty, or a hundred feet, to either side of the central line according to circumstances.

These examples may be considered very simple and unmeaning; but they serve to illustrate the principle of binocular vision quite as satisfactorily as if we had recourse to expensive instruments or apparatus. Our two eyes, under ordinary circumstances, perform their duties so readily, so perfectly, and, to ourselves, so unconsciously, that we scarcely ever think of them as being in reality a pair of the most beautiful optical instruments. Nor does it occur to us that each external and visible eye transmits to the internal and invisible eye a separate picture, or image, of the objects within its range. Two distinct pictures are, however, admitted into the darkened chamber behind the eyes, although one picture only is seen. The inner eye is supplied with machinery for making suitable adjustments, so that two dissimilar parts, or images, of the same object are instantly combined and converted into one. Nothing is more certain, in following out the experiments with the card-board and the plumb-line, than that in looking at an object with both eyes there are parts, on the left hand of the observer, which it is physically impossible should be seen with his right eye, and *vice versâ*. The nearer the object is to the observer, the more readily is this law determined. Hence, therefore, it is plain that the images, or pictures, received upon the retina are not exactly alike; and yet they are so instantly and perfectly united

* It is probable that the habit of shutting the left eye, when plumbing objects, might be the cause of this apparent difference in the power of the eyes. The writer is not sure that it exists in all persons alike.

that we never detect any difference, and never should know that more than one picture had entered the eyes. So is it with the ears. The softest whisper, or the loudest report, whether entering both ears with equal force, or one ear with greater force than the other, is so perfectly equalized on the inner ear, that we are conscious only of one vibratory impression, although the external ears are twofold in their mechanism.

If we try and apply these principles to the Stereoscope there will be no longer any difficulty in understanding it. Obtain two pictures, or diagrams, of any particular object in such forms as it would actually present at a certain distance, when viewed by each eye separately, or, in other words, let the pictures vary in perspective to a given angle. Such pictures, if taken for Mr. Wheatstone's reflecting Stereoscope, when placed in the instrument and viewed by both eyes, will so unite, that a few lines traced upon paper seem to stand out in full relief; two separate pictures of a solid being apparently changed into the object intended to be represented. Nor is this all—the real pictures cannot be seen in the places they actually occupy; whilst the combined image is seen at a part of the instrument where there is no picture of any kind. (Fig. 1, *a*.)

In the Lenticular (Sir David Brewster's) Stereoscope the process is greatly simplified. The pictures being prepared, as in the former case, expressly for the instrument, are viewed by both eyes; but they are combined by lenses made for the purpose (in reality semi-lenses), each of which turns the line of vision in an angular direction inwards, where only one picture is seen, (*b* Fig. 2,) resembling a solid.

Whatever be the process employed to explain the phenomena of binocular vision, it must be understood to consist of certain arrangements by which the eyes are compelled to do something of the same sort of work, *outside* the head, which they are in the constant habit of doing *inside*. The dissimilar image of an object, entering

each eye, is by the natural process of vision turned aside, in an angular direction towards the centre, and there combines and forms a perfect image within the head. By the means we have described, a similar result is, by artificial means, produced outside the head. A little practice in the management of the eyes will enable a person to combine stereoscopic pictures without the aid of an instrument; but in that case three pictures are visible—that in the centre being the true stereoscopic representation of the fainter images on each side.

Viewed only as an instrument for occasional recreation or amusement, the stereoscope occupies an important place. Applied to higher objects of study, and especially as an auxiliary to the various branches of photography, it is as useful as it is beautiful, adding to our pleasures at the same time that it helps to increase our knowledge.

Section CIII.—Photography.

A good picture and a good likeness have very different meanings. In a picture there may be everything to satisfy the most skilful artist; but it may be entirely imaginative;—true to nature in its general effects, and made so by a process, apparently, the least likely of any to realize the painter's wishes. A portrait is a different affair. Here, however great the skill, or beautiful the colouring, they will go for nothing unless the copy resemble, as nearly as possible, the original. We say as nearly as possible, because the utmost perfection of art, and study, and laborious application, necessarily leave something to be supplied by memory, by affection, by imagination, or by actual comparison, as the case may be; nothing being more difficult than to transfer to a flat surface all the lights and shadows, and relative proportions of the real person, or scene, or object.

It was a happy thought, or rather a succession of thoughts, which led to the discovery of the art of Photo-

graphy—a term derived from two Greek words, *phos*, light, and *grapho*, I delineate;—signifying, as thus employed, drawing or delineating by light. In its more popular application it means making sun-pictures on paper, glass, metals, or other substances, variously applied or employed.

The sensitiveness of chloride of silver to the sun's rays was known two hundred years ago, and it is fifty years since some experiments were made demonstrating the possibility of producing what are now called photographic pictures. But although it was thus ascertained that impressions could be obtained on paper, and other substances, first rendered sensitive by a salt (nitrate) of silver, it was not then known by what means the action of light could be arrested, and a picture, changing as quickly as thought, be fixed at any desired moment so as to make it permanent. It was not till 1839 that this important discovery was made, or, at any rate, it was in the beginning of that year it was first made public; MM. Niepcé and Daguerre, in France, and Mr. Fox Talbot, in this country, having published the results of their respective experiments about the same time. Many new processes have since been discovered; the fruits of earnest investigations in this new field of labour—a field already become co-extensive with civilization. It presents an interesting object of study to the amateur, as well as the practical photographist; and one not soon likely to be exhausted. Even now it would be difficult to enumerate the various substances which are used, the number of chemical changes which are ascertained to take place, and the manipulations necessary for giving due effect to such changes.

Referring to what has been said about the refraction, transmission, and reflection of light, the colours of the spectrum, and the forms and uses of lenses (see pp. 48, 57, 64, 110), we will try to describe just so much of Photography as to make the subject intelligible. Should we

succeed, and the reader be thereby encouraged to seek additional information, that can be easily obtained.*

Take a double-convex lens, either a reading-glass, or the object-glass of a small telescope, and look into it attentively, and a distinct and justly-proportioned miniature portrait of the observer will be seen, apparently a few inches behind the glass. Continue to look steadily at the lens, and another image will be seen, smaller and fainter than the first, but in an inverted position, that is, head downwards, and apparently in front of the lens. These reflected images will serve to convey a tolerably correct idea of the process by which Photographic portraits are produced.

A Camera (*camera-obscura*—darkened chamber) is an essential part of Photographic apparatus. It consists of a portable box, with a lens at one end, and suitable arrangements for adjusting it to the focal distance. In this box the sensitive objects are placed, whether metallic plates, or paper, or whatever they may be; means being provided for excluding and admitting light at the proper time and place. Let us suppose that a camera has been placed and adjusted at the proper distance, opposite to a person of whom a Daguerreotyped portrait is to be taken. A silvered-plate, prepared in a peculiar manner, being introduced whilst the camera is darkened, and fixed in such a situation as to receive upon its surface the reflected image of the person in front, the screen or curtain is removed from the lens, and in a very few seconds the portrait will be impressed upon the plate. Let it be noticed that a *good likeness* is by no means certain of attainment. There are many conditions which have to do with the greater, or less, distinctness of the picture; its fidelity as a resemblance of the original; and the accuracy with which the various details, as the hands, the dress, the

* *A Guide to Photography.* W. H. THORNTHWAITE. London.

seat, or the drapery, may be represented. The quantity of light admitted to the room, the direction in which it falls upon the countenance, the state of the atmosphere, the degree of sensitiveness of the plate, the accuracy of the adjustments, must be all taken into account as distinct from the skill and experience of the operator. Nor must it be forgotten that the sitter has his part to perform. The most natural and familiar form and expression of countenance are necessary for the production of what would, by friends, be recognised as a likeness. An uneasy posture, a forced effort to look more amiable, or pleasant, or cheerful than usual, is sure to be a failure. The sun paints the picture accurately, and without flattery; but it does it so quickly, that if there be not quietness and a certain amount of self-command, the portrait will represent a confused embodiment of several successive changes. Hence repeated trials are often necessary, before anything deserving the name of a good likeness can be obtained. These exercise the patience of the operator and of the sitter. If in the latter there arise a feeling of disappointment, or dissatisfaction, it will be much the wisest plan to postpone further attempts until a future day. Health, cheerfulness, good humour, and a becoming dress are all very necessary.

The success of Photographic operations depends on many apparently trifling circumstances. Observation and experience are important elements, whatever be the skill, or taste, or knowledge otherwise possessed. The mechanical, or merely manipulatory, parts of this beautiful art may be possessed in the greatest perfection, but these are not sufficient. There must be a certain amount of optical and chemical knowledge, an eye sensitively alive to quantities and qualities of light, an habitual observation of the changes of the seasons, the influence of clouds and other meteorological phenomena, and the direction and variable properties of sun-light at different periods of the day.

The impression, or rather change, produced on the

surface of the prepared plate, whilst in the camera, and which, eventually, may prove to be a good representation of the features of the person who sat before it, must not immediately be exposed to the light. The portrait is there, but whether good or bad cannot yet be known. To expose it to the light would destroy it entirely. Several processes await it before this can be permitted. The picture must first be made visible, or, as it is termed, 'brought out,' the excess of sensitive coating removed, and the portrait fixed. To effect this the plate must be heated, mercurialized, (exposed to the vapour of mercury,) then repeatedly washed, and, lastly, covered with a film of gold.

This must suffice as the best account we can give, in such few words, of the general principles of photography. We have referred particularly to the Daguerreotyping process, because it is that most familiarly known. There are many other processes—the Talbotype* especially—which are very extensively practised, and with a degree of success which seems to be almost perfect. They have cheapness and simplicity, as well as beauty and facility of execution, to recommend them.

Admitting, most cheerfully, that it is possible, at a favourable moment, to arrest and permanently fix on a metallic plate a very exact resemblance to the human countenance, we still think that photography has more important uses, and more appropriate spheres of action, in representing scenes and objects whose outlines, as well as the included parts, are unyielding, and at rest. Here exactness in the proportions and the perspective is of the utmost value, and, with ordinary precautions, is readily attained. The absence of colour is the chief defect; but this can more easily be dispensed with in representations of landscapes, of buildings, or of the memorials of antiquity, than in family portraits. Photography, in portrait-

* Known also as *Calotype*, from two Greek words signifying 'beautiful picture.'

making, is, in a certain sense, too rigidly faithful. The sun makes no allowance for defects or mistakes; the blemishes being as strongly marked as the beauties. The difficulty in Daguerreotyped portraits is to preserve the vivacity of the eye, and to light up the countenance with even an apology for a smile.

The Stereoscope (page 361) has already proved of great service to photography. Converting a picture into something more than a picture, and imparting to it all the appearances of a reality; it is not too much to expect that the beautiful art we have been describing will, by means of that instrument, be very much improved, and simplified, and extended.

It has frequently been said that coloured photographs ought to be, and would be, produced as quickly as those to which we are now accustomed. There has hitherto been a difficulty about this; various attempts having been made, but with little prospect of success. Colouring by hand has been resorted to, and, in many instances, only to disfigure what would otherwise have been a good likeness. About a year ago it was stated, on what at the time appeared to be good authority, that a colouring process had been perfected in America; all the tints and shades of colours (excepting yellows) being easily rendered permanent by light only. This account has not been confirmed, nor do we believe that any of the (prismatically) coloured pictures have been seen in this country.

Whilst we write this (November, 1852) it is announced that M. Niepcé, the original inventor of the Daguerreotyping process, has at last succeeded in obtaining colours, and fixing them, more or less permanently, in the camera. The experiments are described as being highly satisfactory; encouraging the hope that, before long, the art of photography will thereby be greatly advanced, and that pictures of all the various kinds will be obtainable in natural colours. The new process is stated to be very simple, and the manipulatory operations easily acquired.

Although there is so much to occupy our thoughts, so

many things in nature and in art requiring constant and untiring examination; yet have we great encouragements to labour, and study, and persevere. The acquisition of knowledge is pleasant in itself, and brings with it a large and an enduring reward. The right application of knowledge is imparting it to others—thus rendering it practically useful. In humble reliance on HIM who is the source of all Wisdom, and Power, and Goodness, let us improve our opportunities. Then may we present the petition—'Establish thou the work of our hands upon us; yea, the work of our hands establish thou it.' (Psalm xc. 17.)

ON THE MICROSCOPE.

SECTION I.—MICROSCOPES AS COMPARED WITH OTHER OPTICAL INSTRUMENTS.

THOUGH all the contrivances by which our perceptions of light, and of those things and properties of things which light reveals, are highly interesting, yet there is a peculiar interest about the microscope which does not belong to any of the others. Spectacles are of great use to those whose eyes are imperfect in their construction, or impaired by age; and the telescope not only extends our view as far as a straight line can reach on the surface of the earth, but it reveals the wonders of the heavens. It shows us the surface of the moon, rugged, dreary, and dry, and as different from that of our earth as we can well imagine one body to be from another; and when we point it on a clear night to the blue dome of the sky, the stars are multiplied beyond what our arithmetic can sum up, or even our imagination picture. We see that the creation is, to our comprehension, infinitely great; and what then must be our thoughts of Him who called the whole into being without aid and without labour! "He spake, and it was done."

But the microscope doubles our enjoyments; actually making known to us another creation, as wonderfully small as that upon which we look with the telescope is wonderfully great. It is, indeed, more wonderful, because more out of the line of our ordinary observation and experience. All that the telescope discloses to us, is disclosed, as it were, to our ordinary vision; and in the most glorious sight that it gives us, we have always the feeling that it is distance only which is overcome, and that, if we could perform the journey, we should get the same sight of the objects with our naked eyes without the aid of the glass.

When, however, we resort to the microscope, the glory which we behold is of quite another kind. The little

dot of mould upon a decaying stem, or a withering leaf, which to our unaided sight is merely a stain of colour distinguishable from the rest of the surface and nothing more, becomes a forest of trees, as perfect in their structures as those which clothe the slopes of our mountains, and give to the landscape so much both of its beauty and its fertility.

And when we compare the size of the seeds of our trees with that of the trees themselves, and find that the germ which, when fully developed, becomes the keel or the mainmast of the most stately vessel, is not half the size of a common pea, how inconceivably minute must we suppose the germs of the individual trees in the forest of mould to be! When we find that their full-grown stature is merely colour to the eye, we cease to wonder why they should, according to their kinds, be found in all imaginable situations, and ready to develop themselves whenever those circumstances occur which are favourable for that purpose.

Nor is the minuteness and multitude of animated beings revealed by the microscope less wonderful. When viewed through that instrument, a drop of putrid water, or vinegar, or of water just tinged with the admixture of the sour paste of flour, is found to contain as many living inhabitants as a parish, or a county. Their formation, too, is as perfect, and their organization as nicely adapted to their element, as in those creatures which inhabit the earth, the air, and the ocean, so that downward as far as the microscope can reach, and we know not how much farther—for we cannot imagine a limit—the display of Almighty power is equally wonderful in the small as in the great.

In the most minute of the microscopic tribes, whether vegetable or animal, we find that they are as true to the law of their being as creatures of a larger growth. The mould which grows in the cells of a decaying apple, or the animalcule that is found in stale vinegar, never comes but in that substance; and never but when the substance

is in the state fitted for its appearance. But when that is the case, the plant or the animal fails not to be there. And if we have once properly informed ourselves of the circumstances under which it does appear, we can predict its appearance again under similar circumstances with the same certainty, and on the very same principles, that we predict the rising of the sun, or the succession of the seasons.

Had the microscope no other recommendation than the pleasure which it thus brings, and the beautiful lesson it teaches, that in the sight of God, the extremes of measure are the same, just as the succession of duration, "A thousand years are as one day, and one day is as a thousand years," it would have abundant claims upon our attention. But it is the beauty of all natural subjects, and of all subjects founded upon nature, that we cannot study them without learning something which is useful to us. There are countless operations in the arts which could not be performed without the use of the microscope; and by the help of it, painters, engravers, jewellers, and many other artisans, are enabled to give to their productions a degree of finish and of perfection to which it would be impossible to attain by the naked eye. We cannot say that the microscope has furnished people with a new sense either for knowing or for doing; but it has so assisted the power of vision, that, in some respects, man is a different creature,—since it gives him a command over the productions of nature which, previous to its invention, he did not possess.

Section II.—Lenses of Microscopes.

Though concave reflectors are essential parts of the microscope in one of its forms, yet the effect is generally produced by convex lenses; and the instrument is, properly speaking, a dioptrical one; so that, to understand the nature of the microscope, it is only necessary to un-

derstand the properties of the lens, as the one has all the perfections and imperfections of the other.

The lenses of microscopes must be on the whole convex, otherwise they would not magnify; but the convexity may be produced in various ways. Thus, the lens may be double convex, or raised in the middle, on both sides; and it may have the same convexity on each side, or it may be more convex on the one side than the other. It may also be plano-convex, or flat on the one side, and raised on the other, or it may be concavo-convex, hollow on the one side, and raised on the other; but in order that it may still be a magnifying lens, the concavity must be less, that is, a flatter curve than the convexity. A plano-convex lens has a greater 'field of view,' that is, admits the sight of a greater number of objects, or a greater part of the same object than of a double convex of equally magnifying power; and of double convexes of equal powers, the one which commands the least field is the *isosceles*, or that which has the convexity equal on both sides. In using a lens which is not isosceles, the flattest side should be towards the eye.

Lenses may be made of any transparent substance that will bear to be shaped and polished, and also stand exposure to the air. The cheapest, and therefore the most common substance, is glass; but it is not the best. The best is that which has the greatest refractive power, namely, the diamond; but its high price, and the labour of shaping and polishing it, are against its general use. Transparent sapphire is neither so costly nor so hard as diamond, and therefore, though still very expensive, both in the material and the workmanship, it is more used, but only for very nice and valuable instruments.

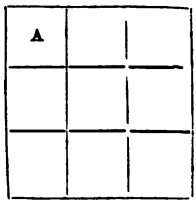
The advantages which lenses made of these gems possess over glass lenses, consist in their greater refractive power. The focus is the point towards which the rays, which are always supposed to fall on the lens parallel to each other, are bent by refraction; and this focus is always situated somewhere in or near the axis of the

lens; that is, in the line passing through the centre of it. Now the more the substance refracts, the sooner must the rays be concentrated to a focus, and consequently the greater must be the magnifying power of the lens, supposing the curve of its convexity to be the same.

It is necessary that beginners in the study, more especially those who are not much conversant with mathematics, and do not consider that lines and objects are real qualities of the same kind, should have clear notions of what is meant by *magnifying power*.

Every object that we can see is seen as a *surface*, having length and breadth. This surface is either a square, or expressible in terms of a square; and in the language of numbers, a square means the multiplying of a number by, or into, itself.

Now the lineal dimensions of an object, as magnified by being seen through a lens, are always inversely as the focal distance of that lens, and consequently, the surfaces, or apparent magnitudes, are inversely as the squares of the focal lengths. The relation of the lines and squares will appear quite plain on the inspection of the following diagram.



Let the square A be any object, and let its lineal dimensions each way be magnified three times; complete the figure, and there are nine squares, each equal to A, or the whole figure is nine times A, or A magnified nine times.

Now it is not because A is a square, that the magnifying in surface is the square of that of the lineal dimensions; for, though it had been any other figure, three times the length and three times the width would still have given nine times the surface.

Neither is it because the lineal increase is three times, that the surface is magnified as the square; for if that increase had been any number, the surface would have been magnified as the square of that number. If the

lineal dimensions are doubled, the surface is magnified four times; if the lineal dimensions are increased four times, the surface is magnified sixteen times; and so of all other cases—always the square of the line.

From the nature of a convex lens, which becomes thinner *equally in all directions* from the centre, or axis, it is evident that when the axis of *any lens whatever* is directed towards the centre of an object, that object must be magnified equally in all directions, and consequently as the square of any one dimension, whether that be considered as length or as breadth.

If the refractive power were perfect, and the rays falling on a spherical surface could be made to converge at the centre of the sphere, then a spherical lens would be perfect; and a microscope composed of such a substance would command the same field of view as the human eye. But no perfect refracting substance is known, nor is it very probable that any one exists.

The crystalline lens in the human eye, and possibly that in the eyes of other living creatures, has, if not a perfectly refractive, at least a perfect, or at all events a wonderful, compensating power; but the compensations in that are produced in the living body, and the lenses of microscopes are made of lifeless matter, so that though human ingenuity may do a little, it can never reach the perfection of the eye; inasmuch as the eye, *of itself*, adapts itself to circumstances,—a property which no human contrivance can possess.

Different kinds of glass have different refractive powers; but when an entire sphere of *plate*-glass of the ordinary composition is used, the focus is not only not the centre, but it is without the sphere, and at half the length of the radius beyond the surface; that is, it is five times the half radius from the surface next the object. According to the increase of the refractive power in diamond, the focus of a diamond sphere should be within the body of the sphere, and half-way between the centre and the surface. Hence, an entire sphere of diamond would not

answer for a microscope, for a great portion of the light would be thrown back in the direction of the object. The refractive power of sapphire is, as has been said, not quite so much as that of diamond, and therefore the focus of it would be nearer the surface.

Comparatively flat lenses of diamond or sapphire, have thus equal magnifying powers with glass lenses of much greater convexity; and it is in this that the superiority of lenses formed of these substances consists. As the part of the lens on which the light falls is a surface, any affection of that surface must be as the square of any lineal dimension upon which the affection depends; and, therefore, the spherical aberrations or errors of the diamond and of glass lenses of the same magnifying power, will be as the squares of their thicknesses.

Now the effect of the spherical aberration is to produce indistinctness in the outlines and confusion in the colours of objects; and in lenses made of the same substance, the tendency to do so is always in proportion to the magnifying power; so that the grand object to be aimed at is the procuring of a lens which, with an equal magnifying power, shall have the most extensive and clearest field of view.

Even the internal structure of the substance of which the lens is formed, has some effect upon the clearness of the sight; and some crystallized substances, which are promising enough in other respects, produce double or even triple images, by the internal refractions of the light in passing through them. But the nature of these substances is one of extended and nice investigation, and, therefore, a mere outline of the general principle is all that is necessary, or even attainable, by those who are not to be professionally engaged in the manufacture or use of such instruments.

Section III.—Estimating the Power of Microscopes.

The relative powers of microscopes, or at least the general principles upon which their powers depend, have been

hinted at in the preceding section; but still they cannot be made practically intelligible without some knowledge of what is understood by the power of a single microscope. Now, the general meaning is, that the object as seen through the microscope shall appear so many times larger than it does when seen by the naked eye at that distance where it is the most distinct, and this is not a constant quantity, but varies in different persons, or in the same person at different times.

Eyes have not only different focal lengths, but they have also different degrees of sensibility or acuteness at those distances at which they see objects best. Both of these qualities in general vary with age; and both of them, but more especially the sensibility, differ in different states of health. Thus there is no means of taking a correct standard, and according to that, making a microscope which shall be the best for everybody.

Those who are in the vigour of life and health, who possess good eyes, and who have made the proper use of them, can see the same object clearly through a very considerable range of magnitude. By such persons, a black spot on white paper, such as this ●, may be brought so near to the eye, that it shall appear of the size of a small, black wafer; and if the paper is gradually removed, it may be seen clear and well-defined, but gradually getting less and less in apparent size, until it at last vanishes in the distance. This is, indeed, the best test of a perfect eye; but there are very few eyes able to bear it. In the majority of cases, the object becomes cloudy both when removed to a great distance, and when brought very near; and there are few eyes in which there is not one range, and that not a very wide one, within which alone the outline and the colours appear perfectly sharp and well-defined. The centre of that range is the proper focus of the eye; and in the average of persons and eyes, it is not very wide of the truth to say that it is at the distance of *ten* inches. So that ten inches may be taken as the standard in estimating the magnifying powers of microscopes.

Here it is difficult to avoid remarking how kind our bountiful Creator has been to our seeming infirmities; and how that which, in one sense, seems an imperfection, becomes, in another, a foundation of beauty, and a source of pleasure. That spherical imperfection of the eye which prevents us from seeing the defined outlines of things far out of, or beyond, the average focal range of ten inches, is the cause of that evanescence of outline, and blending of subject with subject at their confines, which renders the landscape so charming, and gives so much mellowness to a group of objects, even at the distance of a few yards. No doubt the *infraction* of light and the increasing volume of air as the distance becomes greater, have their effect; but still, much is owing to what we might call the weakness, or imperfection of the eye; and were it not for the manner in which this clouds and colours and blends outline with outline, we should lose much of the charm in viewing real objects, just as we feel no pleasure in looking upon a picture in which the outlines are hard and sharp. In such a picture nothing is felt to have life. Trees, mountains, the water itself, appear as if they were chiselled in stone; and animals and human beings, how true soever may be their outlines, and how accurate soever their colours, are no better than tinted statues. There is no motion in hard-lined objects. The cascade, though its curve may be geometrically true, is fixed in ice, the sky is iron, and the clouds brass. Nothing will breathe. We feel as if the forms were animated no more; but left to moulder by the casualties of time without removal, and without renovation.

Ten inches we have assumed as the average standard for the natural sight of such microscopic objects as are of sufficient magnitude for being seen by the naked eye. But there are many microscopic objects, and those the most wonderful and instructive of the whole, of which the unassisted eye can take no cognizance. Indeed, in so far as any object, or part of an object, is properly microscopic, it cannot be at all seen to perfection by the eye at

any focal distance. If we could see it perfectly by the eye alone, there would be no need for the microscope. To magnify an object which we could see well enough without that operation, would be idle; inasmuch as we could thereby learn nothing more than the power of the instrument, and this we could ascertain better by other means, as the maker could tell us, without any waste of time or trouble.

The proper, and indeed the only *use* of the microscope, is to show us what we cannot see without its aid, namely, objects and parts of objects which are too small to be distinctly seen by the naked eye. Whatever portion the focal length of the lens, that is, the distance at which it gives a proper view of the object, is of ten inches, the lens will magnify that number of times in line, or the square of that number of times in surface. Thus, if the focal length be one inch, the lens will magnify ten times, and if a quarter of an inch, forty times in line; but the first of these will be magnifying the surface of the object one hundred, and the second will be multiplying the same 1600 times.

If we think of the object magnified as a solid body, the thickness will have the same increase as the length or the breadth; and the increase of the solid will be as the cube of the lineal dimension. Thus, 10 in line will produce 1000 in solidity, and so of other cases in the same proportion. It is necessary to attend to these distinctions; and when it is said that a microscope magnifies any number of times, it should be mentioned whether the line, the surface, or the solidity is understood.

The most powerful magnifiers that have been made of glass, have been about the 60th part of an inch focal length; and in them the field of view is so exceedingly limited, as not to take in the whole of scarcely any known object. Such a lens is usually made a double convex, and the following are its magnifying powers:

	in line	surface	solid
times	600 .	360,000 .	216,000,000.

When diamond is the material, a higher power may be obtained, with even a wider field and a clearer vision. Sapphire lenses have been made with a focal distance of one 100th part of an inch; whose magnifying powers are—

1000 . 1,000,000 . 1,000,000,000.

The thousand millions' increase in volume, which is seen in directly viewing the object through one of those lenses, is a number of times of which the human mind can form but a very vague and imperfect notion; and yet of the many small objects which the instrument reveals to us, not only the whole, but all the individual parts, have their solid contents magnified in the same proportion. Of these parts of objects, many, and indeed most, are organized, or made of parts, and even the markings which the most powerful glasses discover in them, are organized parts. These not only admit of further subdivision, but actually *fine* off, till in their continuity they defy the instrument, and yet we know, from analogy, that they are again separable into countless numbers of smaller parts.

Thus, when we come to the very extreme of human ingenuity, (and these lenses are wonderfully ingenious contrivances,) we are very far from having reached the boundary of nature. For aught that we know, there may lie greater variety beyond the ken of our most powerful instruments than there lies between the utmost depth into space which the telescope can penetrate, and the object, or fraction of the object, which is not cognizable till the solid contents of it have been magnified a thousand millions of times.

When an object just becomes visible with a certain magnifying power, we may safely conclude that it is as many times less than the least object that we can as plainly see with the naked eye, as the number of that power. But we cannot so easily say what are its absolute dimensions, because we cannot accurately measure the dimensions of the smallest object that is visible at the distance which we assume as our standard.

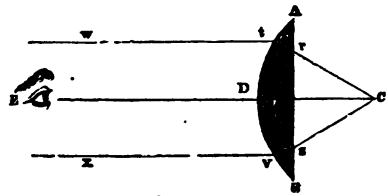
Section IV.—The Kinds of Microscopes.

The kinds of microscopes, in their principle, are refracting and reflecting, those of the latter kind only partially deserving the character, as they have refracting eye-glasses. The kinds, according to their construction, are simple, compound, and solar.

SIMPLE MICROSCOPES.

A simple microscope consists either of a single lens or of two or more lenses. The object of the last is two-fold —either to obtain a greater magnifying power, or to convert the spherical aberration and remove the colours produced by one lens of great magnifying power.

The simplest of all microscopes is a single plano-convex lens, fitted in such a frame as may be most convenient for the purpose that it is intended to answer. As in using such a microscope, it is the object, and not the eye which is placed in the focus of the lens, the flat side of the lens must be turned toward the object, and not toward the eye, as formerly stated, when we were speaking of the power which a lens gives to the eye. The rays from a point of the object fall divergingly upon the plane surface of the lens, and are refracted towards the perpendicular, in proportion to the refractive power of the substance of which the lens is made; more in the heavy optical-glass than in common glass; more in sapphire than in the heavy glass; and more in diamond than in sapphire. When they fall on the convex surface they are again refracted towards the axis, and the object is properly adjusted to the focus when they come to the eye parallel to each other. Hence, if the lens is of a low power, a considerable range of distance is allowed to the eye, but when the power is great, the smallness of the field of view, and quantity of light transmitted through the lens from the object, render it necessary to bring the eye nearer. The following figure will show the way in which the light from a point in the object comes through such a lens.



In this figure, A D B is a section of the plano-convex lens, C is a point of any object in the focus of the lens, C r, C s, are two rays which fall on the plane side at r and s, and are then bent towards C D, the axis of the lens at angles made up of the refractive power and the angles at which they fall taken jointly; at t and v they are again refracted towards the axis, and if the object is in the focus they will then be parallel, as t w and v x. These two rays would not enter an eye of the size, and in the situation of that at E, as that could receive only a parallel beam equal in action to the opening of the pupil.

If the lens is a double convex, as common glasses for very simple microscopes, the only difference in a lens of equal magnifying power will be, that the rays will be more refracted at the surface next the object, and less at that next the eye; but in this case the spherical aberration will be increased, as it arises from two sources, whereas, there is no aberration produced at the plane surface of the lens in the figure.

Two plano-convex lenses give a greater field, as there are two convergencies at which there are refractions without spherical aberration; but as the light has to pass through double the number of surfaces, the intensity is diminished. Still they are, upon the whole, preferable to one double convex of the same power as the two. Two double convexes increase the power but they diminish the field in the same proportion. A greater number of double convexes render the field still narrower; this may be exemplified with the common pocket magnifying-glass, with two or three lenses in separate folds. Look at parallel lines, such as the clear sky of a line-engraving.

The least power will show straight lines nearly parallel over its whole opening; in the next, the line will get a little wider and indistinct towards the sides; and in the highest power, the lines will open at each end, as if they were arches of circles. Put all the glasses together, and the lines will become quite confused, excepting a very small portion at the centre.

There are various other contrivances for the lenses of single microscopes, one principal intention of which is to increase the field of view, and another to counteract the spherical aberration and colouring. For the first of these objects, a double convex and a double concave lens are employed, the first nearest to the eye. The magnifying power of such a combination is the difference between the magnifying power of the convex lens and the diminishing power of the concave; but it takes in a wider field than a single lens equal to that difference. The second object, that of removing the cloudiness and colour, is obtained by a combination of convex and concave lenses formed of glass, having different refractive powers. The forms of these depend a good deal on the nature of the materials that are used, and the degree of magnifying power that is wanted. The single lenses of diamond or sapphire may be regarded as forming the very best microscopes, where a very great power is necessary.

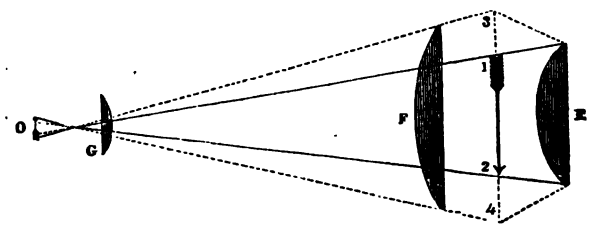
COMPOUND MICROSCOPES.

Even when two convex lenses are used in a simple microscope, there is only one image of the object formed, as both lenses are made conducive to the same purpose—that of bringing divergent rays to a parallel direction. In the compound microscope, on the other hand, there is an object-glass, by means of which the rays of light are concentrated, so as to form an image in that focus of the eye-glass which is most distant from the spectator; and there the eye-glass renders the divergent rays of that image parallel, in the same manner as the simple microscope. The object-glass and eye-glass must thus be

farther asunder than the sum of the focal lengths, in order that an image may be formed, and the object must be placed in the focus of the object-glass.

The chief advantage of the compound microscope is the extent of field that it commands; and this field may be further increased by interposing a field-glass between the object-glass and the eye-glass, which increases the convergency and enlarges the field; but as the instrument performs two separate operations, it is not so correct as the simple microscope. It is, however, better adapted for popular purposes, in which great accuracy is not required, as it will show the whole of an insect, small flower, or other object, of which only part can be seen by a simple microscope of the same magnifying power.

The following diagram will show the arrangement of the glasses in a compound microscope.



O is the object, in the focus of the object-glass G, 1 2 is the inverted image of the object, formed in the focus of the eye-glass E. If the eye-glass just takes in the extent 1 2 of the image, that is, a circle of which 1 2 is the diameter, then the application of the field-glass F will extend the diameter to 3 and 4, or make the field a circle having that diameter.

The compound microscope is generally placed vertically, with the eye-glass at the upper end; and on that account it is necessary to cast a strong light on the object, by means of a reflecting mirror; but in using the instrument, the mirror should be placed obliquely, and not so as to throw the light upwards into the tube that contains the lenses.

SOLAR MICROSCOPES.

A solar microscope consists of a condenser and a magnifier, which have some resemblance to the two parts of the compound microscope, and, like that, it requires a reflector.

The reflector throws the light of the sun upon a very powerful lens of large diameter, and this lens condenses the solar rays, in the same manner as is done by a burning glass. The object is placed inside the instrument, not exactly in the focus of the condensing-lens, for the heat there would be sufficient to destroy or alter the condition of the objects, but still sufficiently near the focus to be very strongly illuminated. The object must either be transparent, or fixed on a transparent substance; and it must be in the inner focus of the magnifier, or object-glass, which may be composed of one lens, or of two lenses, at pleasure.

Beyond the outer focus of the magnifier, one inverted image is formed, and this image, the surface of which increases as the square of the distance, is received on a screen placed in an apartment, into which no light is admitted excepting what passes through the instrument.

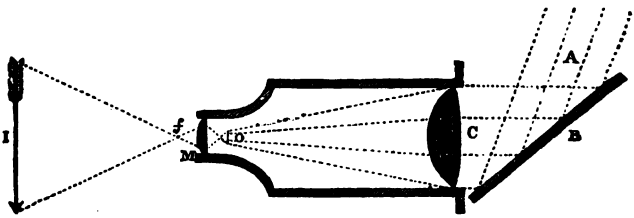
The magnitude of the image at an equal distance depends on the magnifying power of the object-glass; and the general brightness, on the power of the condenser. If, however, the power of the object-glass is great, and the screen on which the image is thrown a plane surface, the portions near the circumference are disproportionally large, and faint and indistinct in the colours. The colours, too, are only those shown by transmitted light, without any of the reflected tints, which are always the most brilliant; so that though the solar microscope be a splendid instrument, it is one of rational entertainment rather than of philosophical research. The finest exhibitions are not those in which the representation is the largest, but in which the size and the clearness are jointly the greatest possible; and as the diameter of a condensing-lens of sufficient power is limited, the most satisfactory sight is

obtained by an image of moderate size, and produced by an object-glass of not too high power, as the smaller the power is there is the less distortion and discoloration in the exterior parts of the picture.

The magnifying power of the solar microscope is estimated, by the relative distances of the object and the screen from the focus of the magnifier, in which the rays cross each other. If the object is distant one-fourth of an inch, and the screen 250 inches, or 20 feet 10 inches, the lineal power will be 1000, the surface 1,000,000, and the solidity 1,000,000,000, or the same as that formerly stated as belonging to the most powerful of the sapphire lenses. A condenser of extraordinary power would be required for affording a clear representation at that distance; and as the picture is really a shadow, the idea of solidity hardly enters into our consideration of it.

The extent of field in the solar-microscope is of great advantage for some particular purposes, more especially for the exhibition of minute living creatures in liquids; and as the motions of these are as much magnified in celerity as their forms are in lineal dimensions, the spectacle is rendered more imposing, inasmuch as not bulk only, but that which we look upon as the most certain sign of life itself, is magnified.

There is, indeed, no instrument which gives so striking a display of the wonders of creation as the solar-microscope; and for this reason, the adaptation of Drummond's



lamp, which answers as well as solar light, is more than a mere amusement. By means of it, an instrument which

could be used only on sunny days, can be used at all times; and if the subjects are well selected, the display can be made a most instructive one, especially to young people.

The preceding diagram will give some notion of the common arrangement of the parts of the instrument.

A is the light of the sun, which is reflected by B, the mirror, to C, the condensing-lens; that lens throws a strong light upon the object, O, which is placed in the focus of the magnifier, M; *f* is the point where the rays cross, and I the magnified and inverted image of the object.

Section V.—Examples of Microscopic Objects.

There are few objects more interesting when viewed by the microscope, than the smaller inhabitants of the water. Perhaps the most interesting are those called *polypi*, which means animals having 'many feet;' a term by no means applicable, as they have no feet at all, unless it be a sort of sucker, by means of which they adhere to other substances, and thus prevent themselves from being carried away by the currents of the water which they inhabit. The appendages from which they have obtained their name are *tentacula*, or instruments for seizing their food. They are also called *zoophytes*, or 'animal plants,' because the arrangement of the colour, in many of the species, has no inconsiderable resemblance to a plant, while the tentacula, when extended, are shaped and sometimes coloured, like the petals or portions of the divided corolla of a flower. Those which are of considerable size are, in popular language, called animal flowers. These are, for the most part, detached and naked, and can move by means of a foot, something resembling that of slugs and snails. In the tropical seas, their colours are often so gay, that the bottom looks like a flower-garden; and there are many curious specimens on the rocky shores of the British isles.

The most curious, however, are those that subsist in colonies; and small and feeble as they are, the works of some of the races are the most gigantic structures created

by living creatures; for, compared to them, the most gorgeous of human buildings are less than molehills in comparison with Egyptian pyramids. They rise from the unfathomable depths of the ocean quite up to the surface, extending hundreds of miles in length, and of very considerable depth, forming, in fact, the solid strata, or ground-work, of groups of inhabited islands; and yet the builders are, individually, nearly or altogether microscopic. The multitudes of creatures so small, which are necessary for the erection of works of so vast size in so short a time, are altogether beyond even imagination; and the comparison of these agents with the effects which they produce, affords one of the most wonderful instances of the Almighty power of the Divine Creator.

But if some tribes of these wonderful creatures form rocks, or rather ridges of mountains in the sea, the colonies of others resemble plants and shrubs. This is the case with those which form the precious corals, and the coral-lines. The substance of these bears a considerable resemblance to that of shells, lime being the earthy or solid part; and the dwellings of the little architects being on the outside. Others consist of countless little cells and pipes, the whole often arranged into singular and highly elegant forms. These, from the great number of openings which they present, have got the names of Madrepores and Millepores; and it is probable that a piece not larger than a man can lift, may have been the dwelling of more living creatures than there are human beings upon the face of the earth.

Sometimes the collected abodes of these little creatures are flexible, and in that state they are called sponges, of which common sponge, so remarkable for the quantity of water that it drinks up, is an instance familiar to everybody. The dwellings of the sponge animals are not, however, the holes which we see in the sponge. These, if we may so speak, are the streets and lanes of their city, and the individual dwellings are in still smaller cells in

the partitions. Fig. 1 is a magnified representation of part of a sponge.

Fig. 1.

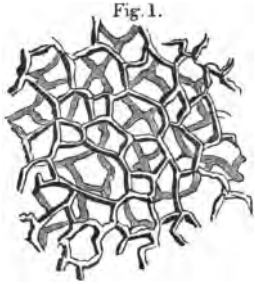
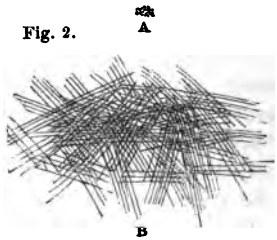


Fig. 2.



'Crumb-of-bread' sponge is a very minute species found among sea-weed on the British shores. In fig. 2 A is the natural appearance, and B a portion magnified. By this it will be seen that the substance consists of minute needles, and small as they are, these irritate the more delicate parts of the skin, such as that between the fingers, till it itches most intolerably.

The following are examples of minute corallines, each showing the natural size, and also a portion magnified.

Fig. 3.

Fig. 4.

Great tooth coralline, fig. 3, (*Sertularia pumila.*) A the natural size, B a magnified portion. The large pear-

shaped portions to the left hand are full-grown animals, having the mouth at the large end and surrounded by the tentacula. The bud-like portions are young, or new branches of the stem.

Sea-tamarisk, fig. 4, (*Sertularia polyzonias.*) A the natural size, B magnified. These adhere in the same manner as the former, but they are larger and less thickly set upon the stem. The full size, the young, and part of a branch, are all shown in the magnified portion. It is to be understood that the tentacula can be either folded together, or expanded, so that the *buds* have them though they do not appear.

Herring bone coralline, fig. 5, (*Sertularia halecyna.*) The animals are on jointed footstalks, or branches which come off nearly opposite, and hence have the name of herring-bone.

Fig.5.

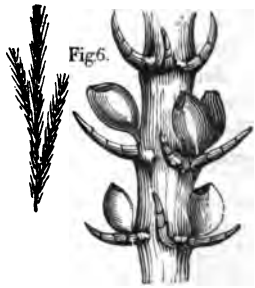


Fig.6.

Lobster's-horn coralline, fig. 6, (*Sertularia antennina.*) The young stems come out in whorts round the old one, like the branches of a fir, or the leaves of woodruff; the animals being like buds in the axillæ of those stems, as is the habit in many plants. In the magnified figure the tentacula are not displayed.

Nit coralline, fig. 7, (*Sertularia lendigera.*) Animals in tubular cells, arranged on one side of the stems, and elongating with age; they increase by the germ, or bud, at the extremity of the stem. When they branch, the

bud divides. The individual animals are produced at the base of the turmical germ.

Fig. 7

In these creatures, though each has an independent existence, there is a mysterious sort of life in the whole stem, which is also divisible into living portions; but though the stem resembles a vegetable one, and the animals appear like buds, their nature and functions are totally different; and the stem lives only while it is in connexion with a living animal, just as is the case with a shell, or with the hair or feathers of an animal.

These corallines adhere to stones or other substances by one root, and form the stem of their dwelling, (which is in fact part of them, as they die if separated from it;) but there are others which dispose themselves over surfaces in separate dwellings. The following are instances:—

A, in fig. 8, is a portion of the frond of a sea-weed, covered with *flustra foliacea;* B is a magnified view of the cells, and C the animal with its tentacula displayed.

Fig. 8.

Fig. 9.

Before it was discovered that these cells were the production and the abode of animals, they were considered

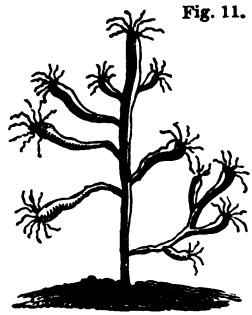
as excrescences belonging to the weed itself; and hence such weed was called 'hornwrack,' which name is now (not very correctly) given to the animal.

No. 9 is another species, which, from the spine on the cells, gets the name of *flustra pilosa*. These animals are exceedingly numerous both in individuals and in species. It is, indeed, probable that no sea-weed is without them; and that every species of weed is the habitation of a different species of *flustra*. The name *flustra* is given because the cells flow or spread over the frond of the sea-weed.

Minute as the coralline animals are, these tiny habitations serve not only to support them at different elevations, so that they all may have food, but also to give a resting-place to other minute animals. Fig. 10 represents the same species as that in fig. 3, (the great-tooth coralline,) supporting several very minute shells.

Fig. 10.

Fig. 11.



Of the food of these wonderful creatures we know nothing, and very little of the mode of their production; but their history may well be considered as one of the wonders of the deep.

Nor is it in the sea only that we find small living things of remarkable structure. They abound also in fresh water, when it is tainted by decaying animal or vegetable matters. Fig. 11 is the brown or green fresh-water hydra,

which is not uncommon in stagnant water, in the warm months. The body of this animal is free, and it can swim by means of the tentacula; but it can also adhere to aquatic plants and other substances. The body is jelly-like, and consists of a sort of little sack, open at both ends; the mouth, with which it feeds rather voraciously, being distinguished by the fringe of tentacula. It is all over instinct with life. The young are produced by buds, and before the separation takes place, a second race of buds often appears on the first, and sometimes a third on the second. Even though cut in pieces, these will produce buds, and soon become perfect animals; and it performs its functions equally well when turned inside out. There are also species of hydra which inhabit the sea. These are usually found on marine plants.

The most interesting microscopic spectacle, however, is a drop of putrid water, when represented on the screen of the solar microscope, because in that we see multitudes of creatures alive and moving undisturbed in their native element; and though when they move, it is generally with such rapidity that neither the means nor the mode of their motion can be very distinctly seen, yet we can contemplate them, and see all the parts and members of their transparent bodies when they are at rest.

Small as these animals are, for there are many thousands in one little drop of water, and yet they are not crowded, there is not the least doubt that each of them springs from a parent germ, even in the cases in which, when in their proper element, other germs are produced at all parts of their body. As the animals do not appear unless there is some kind of animal or vegetable matter in a state of decay, and as they never fail to appear when that is the case, and the weather is sufficiently warm; we may be assured that all animal and vegetable substances are full of these little germs, which only wait the proper circumstances for awakening into life, just as moulds and fungi grow upon the same matters when they begin to decay. As every kind of decaying matter has its peculiar

fungus, there is no doubt that the infusion of every kind of matter in water produces its particular animal, though the life is in the pre-existent germ.

Thus, when we use the microscope aright, it becomes one of the most instructive of instruments; and the wonders of one little drop of water are as great as those of the systems of suns and planets which career through the immensity of space. God is manifest in all created things; and while we cannot help admiring his power and his wisdom, we find every creature so admirably adapted for enjoyment, that we must as irresistibly acknowledge his mercy and his goodness.

ANALYTICAL INDEX.

TEACHERS, who may use this volume as a class-book, if they wish to have a series of questions for examination on the several sections, can easily turn the articles of this Index into such a series, by prefixing the words "What is?" or "Why is?" or any others that the sense may require. These articles do not embrace nearly all the points which may be made subjects of useful interrogatory; but the judicious teacher will find no difficulty in varying them, or interpolating others, as he may think necessary.

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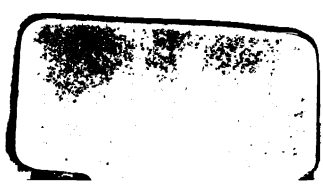
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